DEVELOPMENT OF A CONCEPTUAL HYDROLOGIC MODEL FOR A SUB-ARCTIC WATERSHED

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INTRODUCTION

The Caribou-Poker Creek Research Watershed began as an Alaskan inter-agency effort in 1969. As more data becomes accumulated, as more hydrologic analysis is accomplished and as a greater variety of activities are carried out on the watershed, there is a need to understand the complete hydrologic system of the watershed. This report describes the development of a general hydrologic system model which describes the runoff occurrence on the watershed. The model will provide a basis upon which to make comparative observations, to suggest changes in the model structure and to point out further measurement needs. A conceptual model study such as this work should not be thought of as a final answer to all systems analysis within the watershed or even the most desirable answer in many cases. There is a definite need, however, for a conceptual model because of the variety of activities and investigators, many of which do not have a complete understanding of the whole system. A complete and flexible conceptual model provides a convenient focal point for all types of investigators, regardless of their background and interest in the overall system.

The Caribou-Poker Creek Research Watershed is located approximately 25 miles northwest of Fairbanks, Alaska. It is about 40 square miles in size and covers a variety of terrain which is typical of Interior Alaska. Other details concerning this watershed may be found in Slaughter (1971). Results of hydrologic data to date has been primarily data collection and reporting (Slaughter, 1972).

The model as it is offered in this report is not intended to be a complete study of conceptual watershed modeling. Rather, the intention is to illustrate the derivation of a conceptual model and illustrate how it is applied to a particular watershed.

GENERAL BACKGROUND

The description of a conceptual watershed model should begin with the definition of the term "model": A representation of real fact by something which contains essential realism but is not real in itself. An important corollary inherent in this definition is that any model of the watershed, short of the watershed itself, must be a simplification of the natural processes operating therein. It follows, therefore, that any model must result in an inaccurate description of the exact watershed processes. A compromise must be achieved between undue complexity and a loss of understanding and undue simplification and the loss of realistic representation.

Modeling activities in hydrology can occur in a variety of fashions, depending on the intent of the investigator. For example, a simple graph of two variables is a graphic model of a process which relates the variables to each other. Any procedure which uses equations, graphs or tables are models of a real process.

In recent years in the hydrologic sciences field, the term "model" has come to mean a relatively realistic representation of either some component of the hydrologic system or the entire hydrologic system as a whole; usually represented by equations and calculated and carried out on a digital computer. The term "conceptual watershed modeling" has come to mean those activities which purport to model, simulate, or explain the simultaneous activity of several components of a hydrologic system such as a watershed.

The purposes of most modeling activities are several-fold. They can be used to forecast or predict some outcome of the system based on measured inputs; to learn about the internal mechanisms of the system; to understand the relationships between the various components of the system; and, to obtain an accurate simulation of the system which will not be used to solve problems directly related to the system itself but upon which other problems depend. An example of the latter is tracing a pollutant through the watershed system. The uses of a model are important. They should be specified when developing the model as the usefulness and context will rely on the specified use. The potency of computer analysis has made possible the great expansion in the power of conceptual modeling in hydrology. It has also made possible a great amount of foolishness and unreliability if the modeling activity is not undertaken with a great deal of care.

Possible difficulties in a modeling activity have been summarized by Amorocho and Hart (1964) as follows:

1. Errors in reporting data.

2. Effects of lumping; that is, putting together phenomena in one package which are in effect distributed in nature.

3. Imperfections in the structure of the model; imprecise or incorrect specifications for the connections between the various components.

4. The non-uniqueness of the simulation process.

The last factor relates to the dilemma which faces any modeling effort. Although one may achieve a good match to the objective function, (matching calculated runoff to observed runoff) there may be a number of other arrangements which would give equally good results but which would be quite different.

The advent of large digital computers in the early 1960's gave rise to a wide variety of modeling activities in hydrology. The present state of the art covers many models, some of which are meant to comprehend only a small part of the hydrologic system and some of which encompass its entire range, including atmospheric and oceanographic aspects. They also range in detail from a relatively simple model encompassing one or two parameters and one or two components to comprehensive models which attempt to realistically simulate the complete physical system of a watershed. This report will not attempt to summarize the many different modeling activities which have been undertaken in recent years. For a summary, the reader is referred to Linsley (1971).

The various hydrologic models may be classified as analytical models, parametric models or physically based models. The analytic models are primarily mathematical configurations which concentrate on a general input-output analysis for one or more portions of the hydrologic system. Usually strict attention to the physical base is not important. Parametric models are those which attempt to establish a stronger physical basis for the structure and makeup of the model but which are still seriously compromised in terms of realistically interpreting the entire natural system. Physically based models attempt to model portions of the complete hydrologic system by solving the hydrodynamic equation for fluid motion. Their most serious drawback is the need for relatively accurate specifications of the boundary conditions in order to obtain good results. These models tend to lead to a proliferation of parameters that are difficult to understand and interpret.

Although there are a number of criteria for good models, there are two which will lead to reasonably good results. The first is a faithful adherance to the principle of parsimony. This can be stated in many ways but is probably best exemplified by Box and Jenkins (1970). They argue very eloquently for models which view parameters which lend themselves to ease of identification and estimation and to checking the model for continual readjustment of the parameters. O'Donnell, <u>et al</u>.(1970) have made the same argument in hydrologic modeling and have illustrated the use of parsimony very well. Other criteria for forming a good model have been advanced by Dawdy and O'Donnell (1964) who argue that a useful model should have a basis in physical reality. That is, although we may decide not to faithfully model the entire complexity of a physical system, we should have a physical basis for our mathematical equations.

Before closing this section, mention must be made of a difficult problem in modeling activity.

An important and difficult problem in current hydrologic conceptual modeling efforts is that of properly estimating the various parameters; the numbers which cause the model to operate in a given fashion. There are essentially two parts to this problem. The first is a proper specification of criteria on which to base an estimate. This includes the decision of when the best estimate is obtained. The second is a proper and efficient method leading to the most appropriate choice or optimum choice of the parameters as indicated by the criteria function. There has been a proliferation of literally dozens of optimization procedures, as they are called, some of which are applicable to hydrologic modeling. The Caribou-Poker Creek model uses a crude but effective method. A more complete explanation is included later.

In summary then, it can be said that computer modeling of watersheds presents many advantages along with a great deal of potential difficulty. There have been errors committed on both sides. Traditional hydrologists have ignored, for the most part, computerized efforts and have continued to use classical, more cumbersome methods because of distrust or misunderstanding of conceptual models. On the other hand, many of the conceptual modelers have become overeager in their application and have caused results which are often quite misleading. Perhaps the spirit and philosophy with which a modeler enters a modeling activity is as important as the details of the numerical result. If the modeler constantly keeps in mind that any model, no matter how simple, is not simple enough and consciously strives for a compromise between the two, success will likely be the result.

THE CARIBOU-POKER CREEK WATERSHED MODEL - GENERAL CONSIDERATIONS

The essential feature of a model of a physical system is made up of two parts - its structure and its components. The structure of a model refers to that property which denotes how things are related to one another, both the means by which they are related and which components are connected to which others. The structure of the Caribou-Poker Creek watershed model is indicated in Figure 1. The component aspect of the model refers to that characteristic which describes how the individual features of the model operate and to the rules by which they relate to other components of the model. Thus, in order to completely understand a model, we must both understand its structure and components. Any model, of course, is incomplete or inoperable without some kind of external input which makes the model go, causes it to deviate from average values or acts as an excitation function. The model itself can be easily derived and indicated by a series of schematic diagrams and equations. However, in almost every case, to carry out the computational effort, resort must be made to the digital computer. Observation of the model is accomplished through observing the various states of the components. In this case, the measure of each component is the amount of water stored within it. They are refered to as the storage components. The components are regulated by the parameters of the model. They also may be thought of as the way we tune the model to relate the input as we perceive it to the output as we would like to have it. The final feature of the modeling is the estimation of the parameters. The estimation procedure refers to the selection of the several parameters in such a fashion so as to achieve a desirable correlation between the calculated output of the model and the measured output of the watershed. The usual output of interest is the streamflow.

A conceptual watershed model can be best understood by application to actual data. Since this is the intent and overall objective of the report, each of the above mentioned factors will be described in turn. The next section describes the considerations and process by which the various factors interplay in the development of the model.

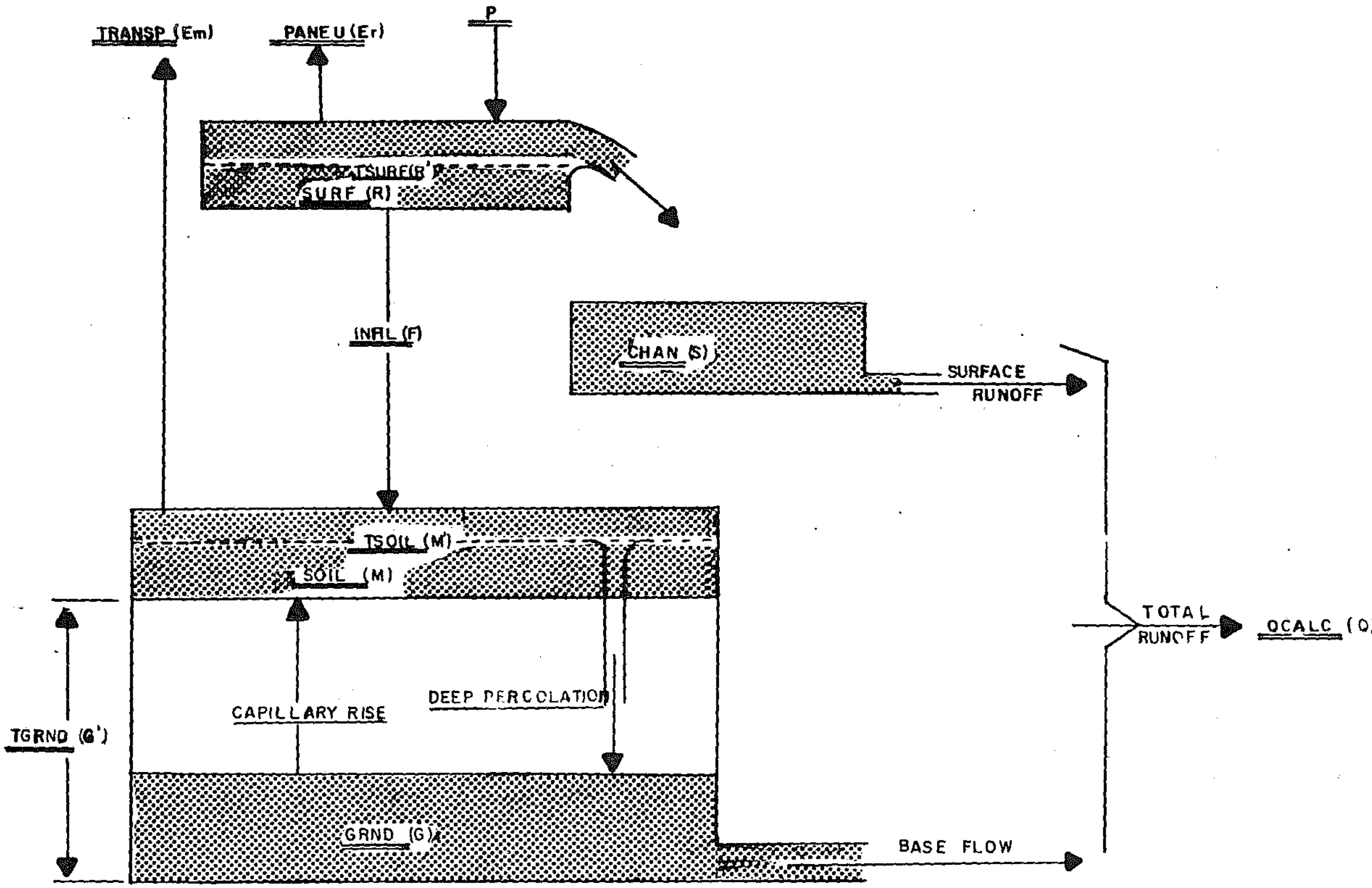

Figure 1: A Schematic Diagram of the Caribou-Poker Creek Watershed Model.

APPLICATION OF THE COMPUTER MODEL TO THE CARIBOU-POKER CREEK WATERSHED

The philosophy and the current status of the modeling art in hydrology have been described in the previous section. As pointed out, model development activity is a many faceted operation and is not entirely automatic. Rather, it involves a great deal of decision-making on the part of the modeler and must be done with a view of the objective to be accomplished with the tools and data at hand. For example, it is infeasible to proceed with a very complex model when only a very limited data structure is available to verify the model. Also, if there is little interest on the part of the users for the complex model, it may be more appropriate to proceed with a much more simplified model. This section will show, by way of application and example, the development of a conceptual model for the Caribou-Poker Creek watershed. Each portion of the model will be explained in turn.

The modeling activity for the Caribou-Poker Creek watershed should be considered as an experimental initial effort. A compromise is achieved between an extremely sophisticated model and a very simple one. The end creation, of course, is a computer program which contains the specification of the structure of the model, the specification of the components, how they relate to each other, and how they relate to the input and the output. Because computer programming has become rather commonplace in many engineering and scientific organizations and because each organization chooses (because of inherent limitations in their own computer capability) to restructure a program, an emphasis on a rigorous presentation of the program was not made. Rather, the flow diagram of the computer program is presented in Appendix B in sufficient detail to be followed by a competent programmer. The FORTRAN program used in the experimental effort is presented in Appendix C.

The remainder of this section will discuss, in turn, each of the components of the model: the input, the structure of the model, the parameters, and the output.

COMPONENTS OF THE MODEL

Each of the components of the model represents a storage of water and certain rules for input into the component and release from it. These are indicated in the schematic diagram of Figure 1, in the computer flow diagram of Appendix B, and the FORTRAN Program itself. The storage components of the model are: surface storage, channel storage, groundwater storage, and soil moisture storage.

The surface storage component is the first part of the model which comes in contact with the primary driving force, precipitation. The surface storage component receives input from precipitation and has output to three sources; via evaporation to the atmosphere, via output to the channel component, and via output to the soil moisture component. There is provision for input from the soil moisture component when conditions are such that the soil becomes saturated and moisture can flow back into the surface component. As seen in the computer flow diagram in Appendix B, the surface storage does not accumulate any storage but receives each days precipitation and distributes it either to the channel flow or directly to the soil moisture according to the specified rules. It also allows evaporation to the atmosphere when water is available in the surface component on a given day.

The channel storage component in conjunction with the surface component makes up the primary runoff reaction to an intense storm while the other two components, the soil moisture and groundwater act on a longer term basis. The primary feature, therefore, of the channel storage component, is short term retention storage and rapid release capability.

The channel component receives water from the surface component and distributes it to the direct output register of the model. It thus forms the primary response to intense precipitation.

The groundwater storage component of the model plays an important role in determining the long term response to the basin. It is responsible for part of the well known recession curve of watershed streamflow. It receives input from the soil moisture block, has possible control on the soil moisture block and provides a direct output to the direct output register of the model in conjunction with the channel component.

The soil moisture component plays a critical role in the operation of the watershed process. It is also the most difficult and complex to measure and to describe by analytic equations. The Caribou-Poker Creek model treats the soil moisture on a very simple basis. This component receives input from the surface block during periods of precipitation and from the groundwater block under certain conditions. It has output via transpiration which is in turn controlled by the potential evapotranspiration. It also provides output to the groundwater block under certain conditions. Thus, the soil moisture component plays a critical role in the operation of the model. It determines the rate and amount of water which is removed from direct surface runoff and provides a mechanism for water to leave the basin via transpiration.

INPUTS TO THE MODEL

The primary input of interest is precipitation. In the application used here, the rainfall amount has been measured at several gauges within the watershed. Precipitation for the period of time for which the model has been applied is indicated in Appendix A. Another important input to the model is that of potential evapotranspiration (the rate at which evapotranspiration would proceed if sufficient water were available to all processes within the watershed). The potential evapotranspiration rate is calculated by the well-known Penman method and is also tabulated in Appendix A.

STRUCTURE OF THE MODEL

The structure of the model is an important feature of any modeling exercise. It is expressed in this model primarily through the computer program and provides the way in which the various components act with each other, with the input and the way in which they provide the output from the model. The structure of the model is indicated by the schematic diagram in Figure 1.

PARAMETERS

As explained in the previous section, the parameters provide the investigator a means of specifying how the model is to operate once the appropriate components and structures have been set up. The parameters may be thought of as the "control knobs" of the model and should not be confused with the storage amounts in the various components. The Caribou-Poker Creek model as reported here is operated by six parameters as follows:

1. FINF, the soil infiltration rate, X(1), [day^{-1}];
2. FSTOR, the channel runoff rate constant, X(2), [day^{-1}];
3. FGRND, the groundwater runoff rate constant, X(3), [day^{-1}];
4. TSURF, the threshhold surface storage, X(4), [million ft^3];
5. TSOIL, the soil threshhold storage, X(5), [million ft^3]; and
6. TGRND, the groundwater threshhold storage, X(6), [million ft^3].

Intertwined with the problem of specifying the operating parameters is that of gauging the parameter values which are the most appropriate or optimum to satisfy a certain criteria. This leads to need of specifying the objective criteria for choosing the appropriate values of the parameters.

Perhaps the most important and difficult problem in current hydrologic modeling efforts is properly estimating the various parameters. There are essentially two parts to this problem: the proper specification of criteria; and the choice of an efficient method of proceeding to the optimum specified criteria. There has been a proliferation of dozens of optimization procedures, as they are called, some of which are applicable to hydrologic modeling. We have chosen a method which, although crude, is quite effective.

The objective function used here is a comparison between the computed streamflow and that observed and recorded by measurements in the field. The objective function, U, is given by

$$U = \sum_{i=1}^{N} [(\text{Observed flow})_i - (\text{calculated flow})_i]^2 \qquad (1)$$

where U equals the desired objective function, i indicates the day, and N indicates the number of days which the function is computed. The estimation procedure attempts to make U as small as possible.

The estimation procedure used in selecting the optimum set of parameters for the model and for the data for which the model was applied is quite straightforward. The procedure selects a given set of values of the six parameters, calculates the total objective function as given in Equation 1 and records it for future reference. The set of six parameter values, then, is moved to a new set of parameter values where a new objective function is calculated. Since there are six variables, fifteen combinations of variables, taken two at a time, exist. If a range of five values for each variable are calculated, a total of 375 computation runs must be made throughout the entire data series, or, approximately 26,000 days of calculation for each set of estimation procedures. Although this seems to indicate that the method is rather cumbersome, it really is quite efficient as a great deal of computer programming time does not have to be spent on a sophisticated method of optimization. The criteria function is then printed on the output in such a way that the effect of change between two pairs can be seen over a range of values. These are termed "parameter maps" and are indicated in Figures 2 through 16.

Examination of these parameter maps indicates both the difficulty in adapting some type of automatic calculation scheme and also the great amount of detail which can be lost by not printing out these maps. This idea has been used in the paper by O'Connell et al. (1970).

The interpretation of these maps and their usefulness in discussing the improvement of the model will be covered further in this section and in the next section. If a high degree of correlation exists between two parameters, either positive or negative, the parameter map will show a sharp trough, a minimum objective function running at a 45° angle across the map. On the other hand, if one parameter has virtually no effect when compared to effects achieved by variation in the other parameters, it will have a trough running vertical or horizontal across the map. If the two parameters are well related to each other, that is, they have good balance and neither parameter dominates the other or is extremely correlated with the other, a well-rounded depression will result around the minimum objective function. The objective parameter maps also point out rather odd irregularities in the objective function surface. Several of the figures (for example, Figures 7 and 9) show certain dips, faults, plateaus, and double optimum points. These configurations probably have some intuitive physical explanation which will not be exploited at this time. The complete set of objective functions for the final run, which include the best set of six parameters on each map, is shown on Figures 2 through 16.

OUTPUT OF THE MODEL

The output of hydrologic models is usually streamflow. The computed values for the best set of parameters and the values as measured in the field are shown in Figure 17. There are, of course, a number of other outputs of the model which are of interest. One is the actual transpiration calculated by

PARAMETERS TO BE VARIED THIS ROUND ARE X(1) AND X(2) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.875E 00	1033.	993.	957.	924.	893.	866.	842.	821.	802.	786.
	0.838E 00	839.	797.	759.	726.	697.	671.	649.	631.	616.	605.
	0.802E 00	694.	653.	618.	589.	564.	543.	528.	516.	510.	507.
	0.765E 00	577.	541.	511.	488.	471.	459.	452.	451.	455.	464.
X(1)	0.729E 00	490.	462.	441.	427.	420.	420.	426.	438.	456.	479.
	0.693E 00	480.	464.	458.	459.	468.	485.	500.	539.	577.	620.
	0.656E 00	479.	489.	508.	537.	574.	619.	672.	732.	799.	872.
	0.620E 00	579.	614.	659.	714.	779.	852.	934.	1024.	1122.	1226.
	0.583E 00	742.	806.	882.	968.	1066.	1172.	1289.	1413.	1547.	1687.
	0.547E 00	964.	1062.	1173.	1297.	1432.	1577.	1732.	1897.	2071.	2253.
		0.173E 00	0.184E 00	0.194E 00	0.205E 00	0.216E 00	0.227E 00	0.238E 00	0.248E 00	0.259E 00	0.270E 00

Figure 2: Map of Objective Function as a Function of Parameters X1 and X2.

PARAMETERS TO BE VARIED THIS ROUND ARE X(1) AND X(3) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.875E 00	1346.	1093.	929.	855.	893.	839.	856.	930.	961.	1011.
	0.838E 00	1088.	870.	740.	700.	697.	679.	718.	786.	813.	890.
	0.802E 00	895.	708.	610.	600.	564.	569.	637.	669.	721.	822.
	0.765E 00	736.	582.	516.	537.	471.	49[illegible].	534.	590.	667.	793.
X(1)	0.729E 00	612.	497.	469.	527.	420.	482.	5[illegible]6.	5[illegible]3.	669.	790.
	0.693E 00	581.	508.	520.	618.	468.	498.	551.	640.	778.	913.
	0.656E 00	648.	616.	670.	808.	574.	675.	697.	819.	941.	1140.
	0.620E 00	809.	819.	913.	1091.	779.	836.	942.	1051.	1235.	1465.
	0.583E 00	1066.	1117.	1251.	1467.	1066.	1145.	1284.	1411.	1627.	1798.
	0.547E 00	1418.	1511.	1685.	1941.	1432.	1554.	1669.	1871.	2035.	2306.
		0.424E-02	0.450E-02	0.477E-02	0.503E-02	0.530E-02	0.556E-02	0.583E-02	0.609E-02	0.636E-02	0.662E-02

Figure 3: Map of Objective Function as a Function of Parameters X1 and X3.

PARAMETERS TO BE VARIED THIS ROUND ARE X(1) AND X(4) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.875E 00	694.	484.	464.	606.	893.	1369.	2030.	2255.	2186.	2190.
	0.838E 00	873.	561.	463.	506.	697.	1048.	1578.	2124.	2341.	2186.
	0.802E 00	1106.	700.	478.	443.	564.	800.	1201.	1768.	2188.	2347.
	0.765E 00	1401.	899.	574.	435.	471.	821.	904.	1342.	1935.	2248.
X(1)	0.729E 00	1759.	1159.	751.	521.	420.	511.	683.	999.	1460.	2067.
	0.692E 00	2181.	1490.	989.	651.	468.	423.	542.	740.	1077.	1551.
	0.656E 00	2665.	1893.	1292.	863.	574.	441.	435.	567.	819.	1133.
	0.620E 00	3149.	2367.	1680.	1151.	779.	515.	429.	449.	583.	854.
	0.583E 00	3749.	2911.	2147.	1530.	1065.	726.	515.	429.	451.	585.
	0.547E 00	4463.	3460.	2694.	1996.	1432.	1009.	701.	509.	436.	448.
		0.864E 07	0.918E 07	0.972E 07	0.103E 08	0.108E 08	0.113E 08	0.119E 08	0.124E 08	0.130E 08	0.135E 08

600
500
600
500
550
450
450
550

Figure 4: Map of Objective Function as a Function of Parameters X1 and X4.

PARAMETERS TO BE VARIED THIS ROUND ARE X(1) AND X(5) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.875E 00	862.	864.	903.	898.	893.	889.	885.	881.	877.	873.
	0.838E 00	736.	739.	703.	700.	697.	694.	691.	689.	687.	685.
	0.802E 00	663.	666.	567.	565.	564.	562.	568.	566.	565.	563.
	0.765E 00	627.	631.	47[illegible].	472.	471.	470.	469.	469.	469.	469.
X(1)	0.729E 00	648.	653.	419.	420.	420.	421.	422.	423.	425.	427.
	0.693E 00	773.	780.	786.	466.	468.	471.	468.	465.	487.	485.
	0.656E 00	997.	1005.	1013.	5[illegible]6.	574.	[illegible]	586.	585.	584.	583.
	0.620E 00	1314.	1323.	1332.	779.	779.	778.	778.	780.	780.	780.
	0.583E 00	1723.	1733.	1743.	1065.	1065.	1057.	1058.	1060.	1061.	1063.
	0.547E 00	1446.	1447.	1429.	1430.	1432.	1434.	1437.	1439.	1443.	1446.
		0.127E 08	0.135E 08	0.143E 08	0.151E 08	0.159E 08	0.167E 08	0.175E 08	0.183E 08	0.190E 08	0.198E 08

450

500

550

600

Figure 5: Map of Objective Function as a Function of Parameters X1 and X5.

PARAMETERS TO BE VARIED THIS ROUND ARE X(1) AND X(6) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.875E 00	1086.	953.	873.	845.	893.	851.	859.	910.	1009.	1048.
	0.838E 00	871.	761.	704.	700.	697.	682.	711.	818.	841.	907.
	0.802E 00	716.	828.	592.	609.	564.	570.	618.	692.	736.	825.
	0.765E 00	59[illegible].	529.	515.	554.	471.	493.	544.	60[illegible].	671.	782.
X(1)	0.729E 00	516.	476.	488.	55[illegible].	420.	470.	515.	565.	6[illegible]9.	787.
	0.693E 00	529.	518.	5[illegible]0.	66[illegible].	468.	499.	552.	[illegible]32.	757.	899.
	0.656E 00	638.	657.	729.	853.	574.	[illegible]26.	692.	803.	929.	1117.
	0.620E 00	840.	889.	990.	1145.	779.	834.	931.	1041.	1216.	1435.
	0.583E 00	1134.	1213.	1344.	1529.	1065.	1140.	1269.	1396.	1602.	1789.
	0.547E 00	1522.	1632.	1795.	2011.	1432.	1546.	1660.	1852.	2026.	2295.
		0.152E 09	0.162E 09	0.171E 09	0.181E 09	0.190E 09	0.200E 09	0.209E 09	0.219E 09	0.228E 09	0.238E 09

Figure 6: Map of Objective Function as a Function of Parameters X1 and X6.

PARAMETERS TO BE VARIED THIS ROUND ARE X(2) AND X(3) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.259E 00	663.	546.	517.	574.	456.	515.	[illegible]	613.	719.	838.
	0.248E 00	641.	525.	490.	553.	438.	498.	536.	592.	698.	817.
	0.238E 00	626.	510.	481.	539.	426.	487.	520.	576.	682.	802.
	0.227E 00	616.	501.	472.	530.	420.	481.	510.	566.	673.	793.
X(2)	0.216E 00	613.	497.	469.	527.	420.	482.	506.	563.	669.	789.
	0.205E 00	616.	500.	472.	530.	427.	490.	509.	565.	671.	792.
	0.194E 00	625.	510.	482.	540.	441.	504.	518.	574.	680.	801.
	0.184E 00	642.	527.	499.	557.	462.	526.	534.	589.	695.	817.
	0.173E 00	667.	552.	523.	582.	490.	554.	556.	612.	718.	839.
	0.162E 00	700.	584.	555.	613.	526.	591.	587.	642.	747.	869.
		0.424E-02	0.450E-02	0.477E-02	0.503E-02	0.530E-02	0.556E-02	0.583E-02	0.609E-02	0.636E-02	0.662E-02

Figure 7: Map of Objective Function as a Function of Parameters X2 and X3.

PARAMETERS TO BE VARIED THIS ROUND ARE X(2) AND X(4) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNUFF

		0.864E 07	0.918E 07	0.972E 07	0.103E 08	0.108E 08	0.113E 08	0.119E 08	0.124E 08	0.130E 08	0.135E 08
	0.259E 00	2547.	1699.	1086.	672.	456.	474.	594.	896.	1379.	2042.
	0.248E 00	2334.	1551.	990.	623.	438.	476.	611.	918.	1397.	2048.
	0.238E 00	2132.	1410.	902.	582.	426.	483.	631.	943.	1417.	2054.
	0.227E 00	1940.	1280.	822.	548.	420.	494.	655.	970.	1438.	2060.
X(2)	0.216E 00	1758.	1159.	751.	521.	420.	511.	683.	999.	1460.	2067.
	0.205E 00	1589.	1048.	688.	502.	427.	533.	714.	1031.	1484.	2075.
	0.194E 00	1432.	948.	635.	498.	441.	561.	750.	1065.	1510.	2082.
	0.184E 00	1288.	860.	592.	489.	462.	594.	790.	1103.	1536.	2091.
	0.173E 00	1159.	784.	560.	497.	490.	633.	833.	1143.	1565.	2099.
	0.162E 00	1045.	722.	519.	514.	526.	678.	882.	1186.	1594.	2108.

450 500 550 600

Figure 8: Map of Objective Function as a Function of Parameters X2 and X4.

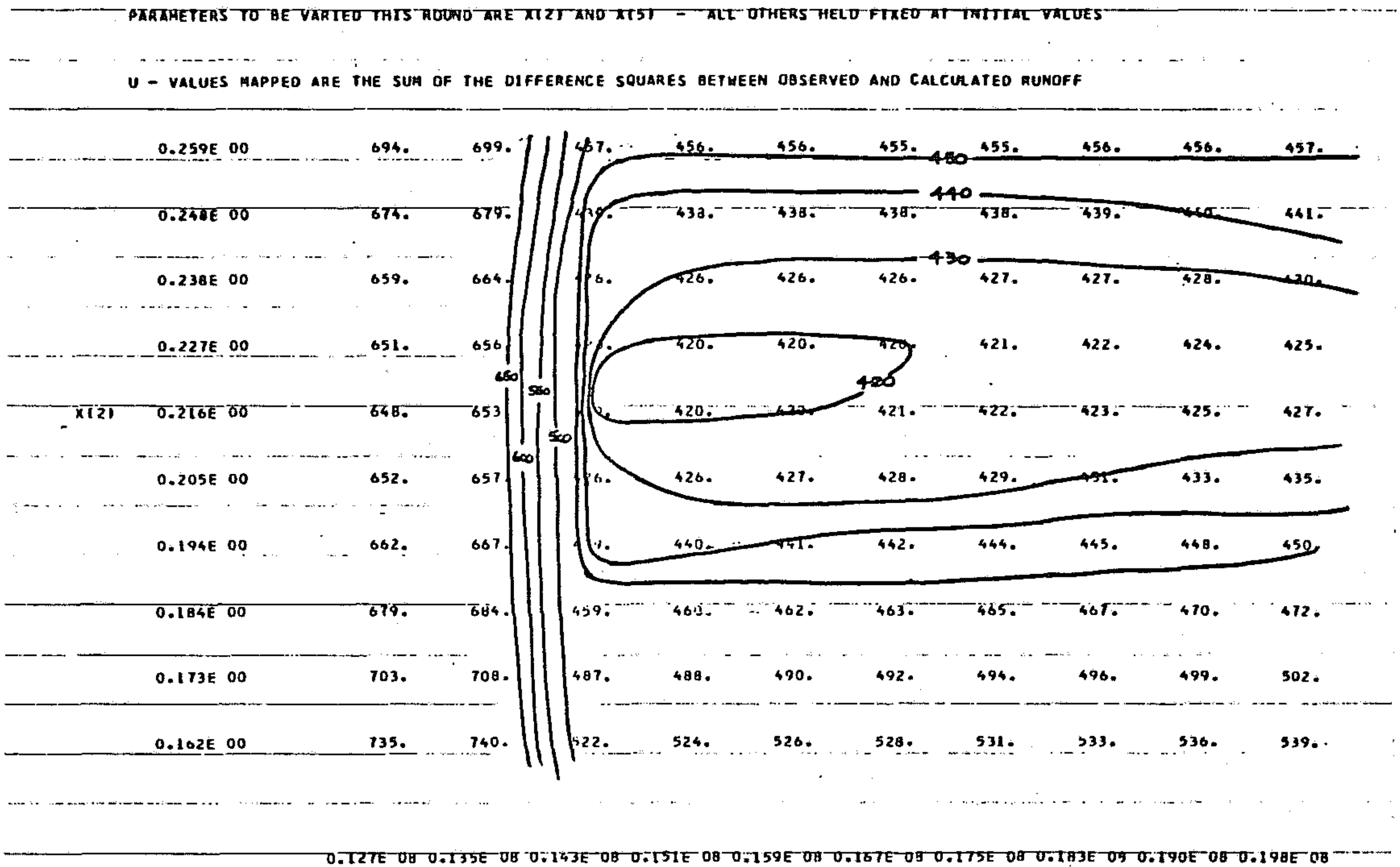

Figure 9: Map of Objective Function as a Function of Parameters X2 and X5.

PARAMETERS TO BE VARIED THIS ROUND ARE X(2) AND X(6) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.259E 00	561.	521.	533.	599.	456.	[illegible]	567.	618.	713.	840.
	0.248E 00	541.	501.	513.	579.	438.	487.	546.	596.	691.	819.
	0.238E 00	527.	486.	499.	565.	426.	476.	530.	580.	675.	802.
	0.227E 00	518.	478.	491.	[illegible]	420.	470.	519.	569.	664.	791.
X(2)	0.216E 00	516.	476.	488.	[illegible]	420.	470.	515.	565.	659.	787.
	0.205E 00	520.	480.	492.	[illegible]	427.	477.	517.	566.	660.	788.
	0.194E 00	532.	491.	[illegible]	[illegible]	441.	491.	525.	574.	668.	796.
	0.184E 00	550.	509.	521.	585.	462.	[illegible]	540.	589.	683.	810.
	0.173E 00	576.	534.	546.	610.	490.	540.	563.	611.	704.	831.
	0.162E 00	609.	567.	578.	642.	626.	576.	593.	640.	733.	860.
		0.152E 09	0.162E 09	0.171E 09	0.181E 09	0.190E 09	0.200E 09	0.209E 09	0.219E 09	0.228E 09	0.238E 09

500 650 450 500 550

Figure 10: Map of Objective Function as a Function of Parameters X2 and X6.

PARAMETERS TO BE VARIED THIS ROUND ARE X(3) AND X(4) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.636E-02	2402.	1738.	1179.	856.	669.	680.	797.	1141.	1436.	1872.
	0.609E-02	2233.	1520.	1048.	705.	563.	616.	812.	1009.	1348.	1822.
	0.583E-02	2018.	1395.	901.	604.	506.	60[illegible].	706.	947.	1319.	1830.
	0.556E-02	1898.	1252.	804.	447.	482.	523.	670.	939.	1353.	1912.
X(3)	0.530E-02	1758.	1159.	751.	[illegible]1.	420.	511.	683.	999.	1460.	2067.
	0.503E-02	2316.	1585.	1042.	688.	527.	55[illegible].	684.	946.	1344.	1880.
	0.477E-02	2040.	1362.	874.	57[illegible].	469.	550.	727.	1036.	1483.	2067.
	0.450E-02	1845.	1222.	789.	546.	497.	633.	859.	1216.	1712.	2347.
	0.424E-02	1731.	1164.	788.	604.	611.	804.	1080.	1487.	2033.	2720.
	0.397E-02	1699.	1189.	871.	746.	815.	1062.	1390.	1848.	2446.	3185.
		0.864E 07	0.918E 07	0.972E 07	0.103E 08	0.108E 08	0.113E 08	0.119E 08	0.124E 08	0.130E 08	0.135E 08

Hand-drawn contour labels: 600, 550, 500, 450, 500

Figure 11: Map of Objective Function as a Function of Parameters X3 and X4.

PARAMETERS TO BE VARIED THIS ROUND ARE X(3) AND X(5) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.636E-02	669.	668.	668.	668.	669.	670.	671.	672.	674.	676.
	0.609E-02	568.	566.	564.	563.	563.	562.	562.	562.	562.	562.
	0.583E-02	585.	591.	496.	508.	506.	505.	503.	502.	501.	500.
	0.556E-02	468.	471.	475.	478.	482.	469.	467.	465.	463.	461.
X(3)	0.530E-02	648.	653.	419.	420.	420.	421.	422.	423.	425.	427.
	0.503E-02	515.	517.	520.	523.	527.	531.	535.	539.	544.	549.
	0.477E-02	467.	467.	467.	468.	469.	469.	470.	472.	473.	475.
	0.450E-02	505.	503.	501.	499.	497.	495.	494.	492.	490.	489.
	0.424E-02	628.	624.	621.	617.	613.	608.	604.	600.	596.	592.
	0.397E-02	837.	832.	826.	821.	815.	809.	802.	796.	789.	783.
		0.127E 08	0.135E 08	0.143E 08	0.151E 08	0.159E 08	0.167E 08	0.175E 08	0.183E 08	0.190E 08	0.198E 08

Figure 12: Map of Objective Function as a Function of Parameters X3 and X5.

PARAMETERS TO BE VARIED THIS ROUND ARE X(3) AND X(6) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

X(3)	0.636E-02	752.	483.	479.	548.	669.	819.	1045.	1270.	1602.	1994.
	0.609E-02	600.	752.	488.	499.	563.	683.	833.	1052.	1271.	1589.
	0.583E-02	510.	592.	738.	489.	586.	570.	686.	832.	1039.	1249.
	0.556E-02	482.	500.	576.	42[illegible].	482.	512.	570.	678.	816.	1007.
	0.530E-02	516.	476.	488.	[illegible]53.	420.	470.	515.	565.	659.	787.
	0.503E-02	612.	520.	474.	477.	527.	418.	465.	518.	555.	633.
	0.477E-02	771.	631.	534.	480.	469.	500.	574.	460.	494.	545.
	0.450E-02	992.	811.	668.	564.	497.	469.	479.	527.	432.	500.
	0.424E-02	1275.	1058.	876.	727.	613.	532.	484.	471.	492.	436.
	0.397E-02	1620.	1374.	1158.	971.	815.	688.	591.	523.	485.	477.
		0.152E 09	0.162E 09	0.171E 09	0.181E 09	0.190E 09	0.200E 09	0.209E 09	0.219E 09	0.228E 09	0.238E 09

Figure 13: Map of Objective Function as a Function of Parameters X3 and X6.

PARAMETERS TO BE VARIED THIS ROUND ARE X(4) AND X(5) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.130E 08	1296.	1296.	1474.	1467.	1461.	1454.	1448.	1442.	1436.	1430.
	0.124E 08	939.	941.	1008.	1004.	999.	995.	991.	987.	983.	979.
	0.119E 08	719.	722.	688.	685.	683.	681.	698.	695.	692.	690.
	0.113E 08	631.	635.	51[illegible].	513.	511.	510.	509.	508.	507.	507.
X(4)	0.108E 08	648.	653.	419.	420.	420.	421.	422.	423.	425.	427.
	0.103E 08	857.	863.	871.	518.	521.	505.	524.	522.	520.	519.
	0.972E 07	1258.	1266.	1275.	752.	751.	750.	749.	749.	753.	753.
	0.918E 07	1847.	1856.	1867.	1169.	1159.	1159.	1159.	1160.	1161.	1163.
	0.864E 07	2622.	2633.	2646.	1757.	1758.	1760.	1763.	1766.	1769.	1772.
	0.810E 07	2548.	2550.	2552.	2554.	2557.	2562.	2566.	2571.	2576.	2521.
		0.127E 08	0.135E 08	0.143E 08	0.151E 08	0.159E 08	0.167E 08	0.175E 08	0.183E 08	0.190E 08	0.198E 08

Figure 14: Map of Objective Function as a Function of Parameters X4 and X5.

PARAMETERS TO BE VARIED THIS ROUND ARE X(4) AND X(6) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.130E 08	1696.	1517.	1391.	1318.	1461.	1374.	1338.	1357.	1406.	1506.
	0.124E 08	1212.	1066.	973.	933.	999.	950.	956.	992.	1094.	1124.
	0.119E 08	864.	751.	692.	685.	683.	676.	698.	801.	822.	887.
	0.113E 08	646.	567.	542.	569.	511.	520.	580.	633.	688.	788.
X(4)	0.108E 08	516.	476.	488.	553.	420.	470.	515.	565.	659.	787.
	0.103E 08	567.	568.	421.	728.	521.	543.	603.	695.	810.	979.
	0.972E 07	808.	850.	946.	1094.	751.	803.	893.	1028.	1165.	1376.
	0.918E 07	1235.	1320.	1457.	1647.	1159.	1248.	1381.	1508.	1717.	1907.
	0.864E 07	1850.	1976.	2156.	2388.	1758.	1890.	2009.	2216.	2399.	2682.
	0.810E 07	2654.	2824.	3047.	3322.	2557.	2668.	2874.	3051.	3332.	3569.
		0.152E 09	0.162E 09	0.171E 09	0.181E 09	0.190E 09	0.200E 09	0.209E 09	0.219E 09	0.228E 09	0.238E 09

Figure 15: Map of Objective Function as a Function of Parameters X4 and X6.

PARAMETERS TO BE VARIED THIS ROUND ARE X(5) AND X(6) - ALL OTHERS HELD FIXED AT INITIAL VALUES

U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARES BETWEEN OBSERVED AND CALCULATED RUNOFF

	0.190E 08	506.	476.	499.	574.	425.	467.	50[illegible].	560.	658.	787.
	0.183E 08	509.	476.	496.	568.	423.	469.	509.	561.	657.	787.
	0.175E 08	511.	476.	493.	563.	422.	472.	510.	562.	658.	786.
	0.167E 08	514.	476.	490.	558.	421.	474.	512.	563.	658.	786.
X(5)	0.159E 08	516.	476.	488.	553.	420.	470.	515.	565.	659.	787.
	0.151E 08	519.	476.	486.	549	420.	467.	517.	567.	660.	787.
	0.143E 08	521.	476.	484.	54[illegible].	419.	464.	500	569.	662.	788.
	0.135E 08	524.	477.	483.	542.	[illegible]	462.	55[illegible].	571.	663.	800.
	0.127E 08	527.	478.	482.	538.	648.	460.	55[illegible].	573.	665.	801.
	0.119E 08	529.	478.	481.	535.	643.	458.	546.	576.	668.	803.
		0.152E 09	0.162E 09	0.171E 09	0.181E 09	0.190E 09	0.200E 09	0.209E 09	0.219E 09	0.228E 09	0.238E 09

Figure 16: Map of Objective Function as a Function of Parameters X5 and X6.

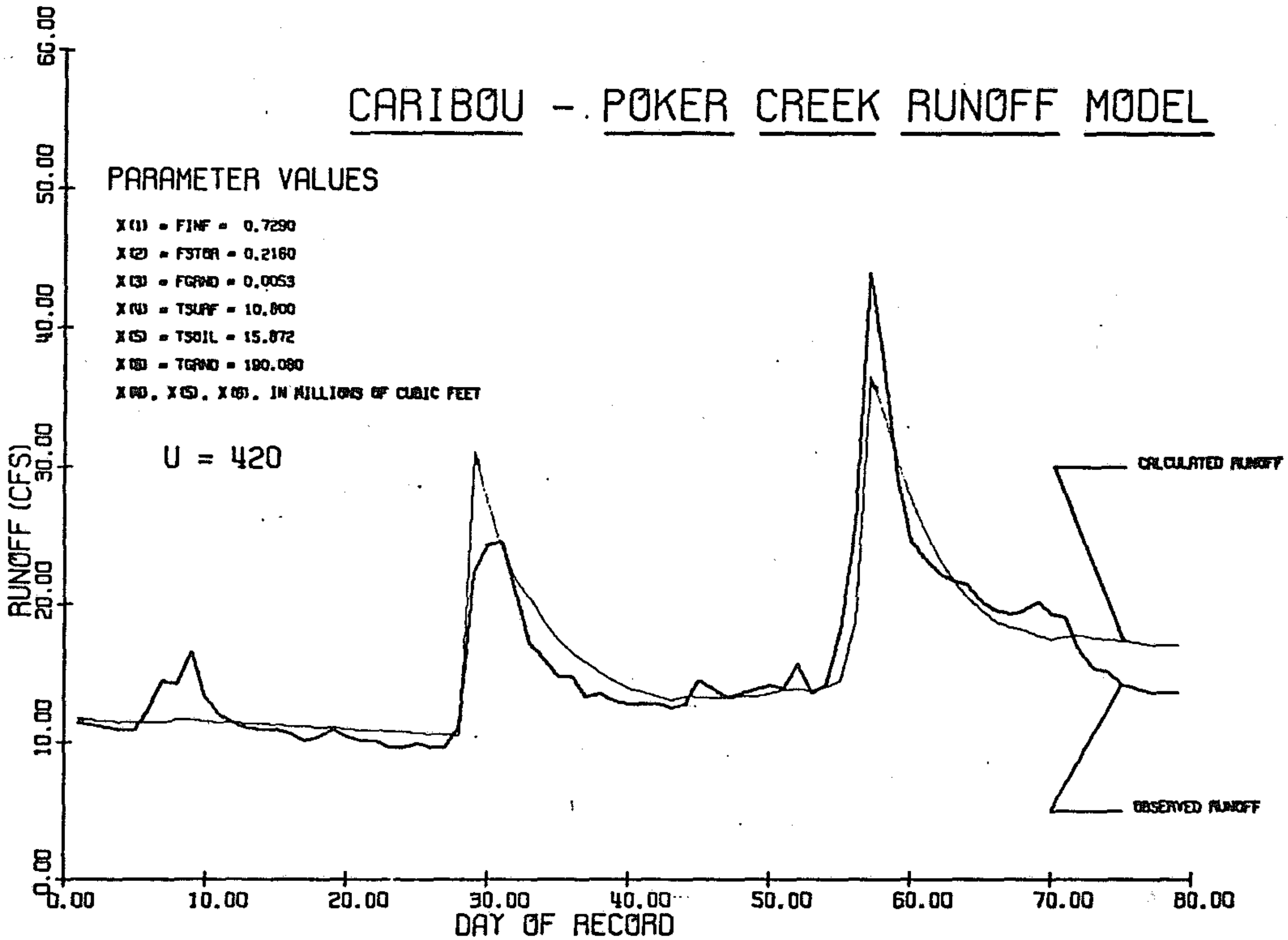

Figure 17: Hydrographs of Calculated and Observed Runoff for the Best Estimate of Parameters.

the model which we have not made a special attempt to tabulate and the various storage components which we have tabulated.

SUMMARY

The previous sections of this report have presented the philosophy, construction and operation of a conceptual watershed model for the Caribou-Poker Creek watershed. The model should be simple and versatile enough to be useful for a wide variety of purposes. The project was not intended to be directed towards a specific aspect of the research watershed, but rather to develop a generalized model. Specific application will be left to further studies and other investigators. The model was applied to the 1971 summer runoff data; several points of interest emerged. These will now be discussed to illustrate several features of the model and to open up several questions which need to be verified by further studies, measurements and investigations. The remainder of this section will discuss, in turn, the interpretative analysis of the parameters, comments relating to the various storage volume plots, particularly in regard to groundwater and soil moisture, and several general suggestions for improvement of the model.

As mentioned previously, the dominance of one parameter over another or an indication of a good balance between pairs of parameters can be interpreted from the parameter maps. The parameters are also compared in Table 1. First, note that the variables Number 1 and 4 are strongly negatively correlated. This is to be expected since an increase in infiltration capacity or a decrease in surface storage before runoff occurs is likely to have about the same effect. Also, Numbers 3 and 6 are highly correlated. This again is to be expected for the same reason. Examining the entire table, we see that neither 5 or 6 dominate the other parameters. This would tend to suggest that 5 and 6 are relatively insensitive to operation of the model and are possible candidates for exclusion if the model were to be simplified. This is especially true with Number 5 which is dominated by every other parameter. Number 6 is dominated by one other parameter and appears to be in balance with Number 1 and Number 2. If one were to modify the model with the objective of simplifying it, the groundwater and soil system would be a good candidate. Because six parameters are already a rather small number for such a complex system as a watershed, it does not appear feasible to combine or readjust any of the other parameters.

TABLE 1

	X1	X2	X3	X4	X5	X6
X1		1	0	-	1	0
X2			3	4	2	0
X3				0	3	-
X4					4	4
X5						6

Table 1 - Indication of dominance of one parameter over another for all combinations; numeral indicates the dominant parameter; 0 indicates a good balance; and - indicates a strong negative correlation.

Examination of the storage volume versus time for each of the various storage components indicate several features of interest (See Figures 18 through 21).

The surface storage and channel storage operate about as expected. The surface storage shows a very sharp rise during a period of heavy precipitation and a very quick fall as the water leaves the surface and goes to the channel storage component. The channel storage shows a more gradual fall as we might expect from experience with typical recession curves.

The plot of soil moisture storage and groundwater storage versus time indicates some rather unexpected results. During the early part of the record, they exhibit some fluctuation with time. However, beginning at about Day 30, both storages increase rather dramatically and continue to increase throughout the rest of the season to the end of the measurement period at

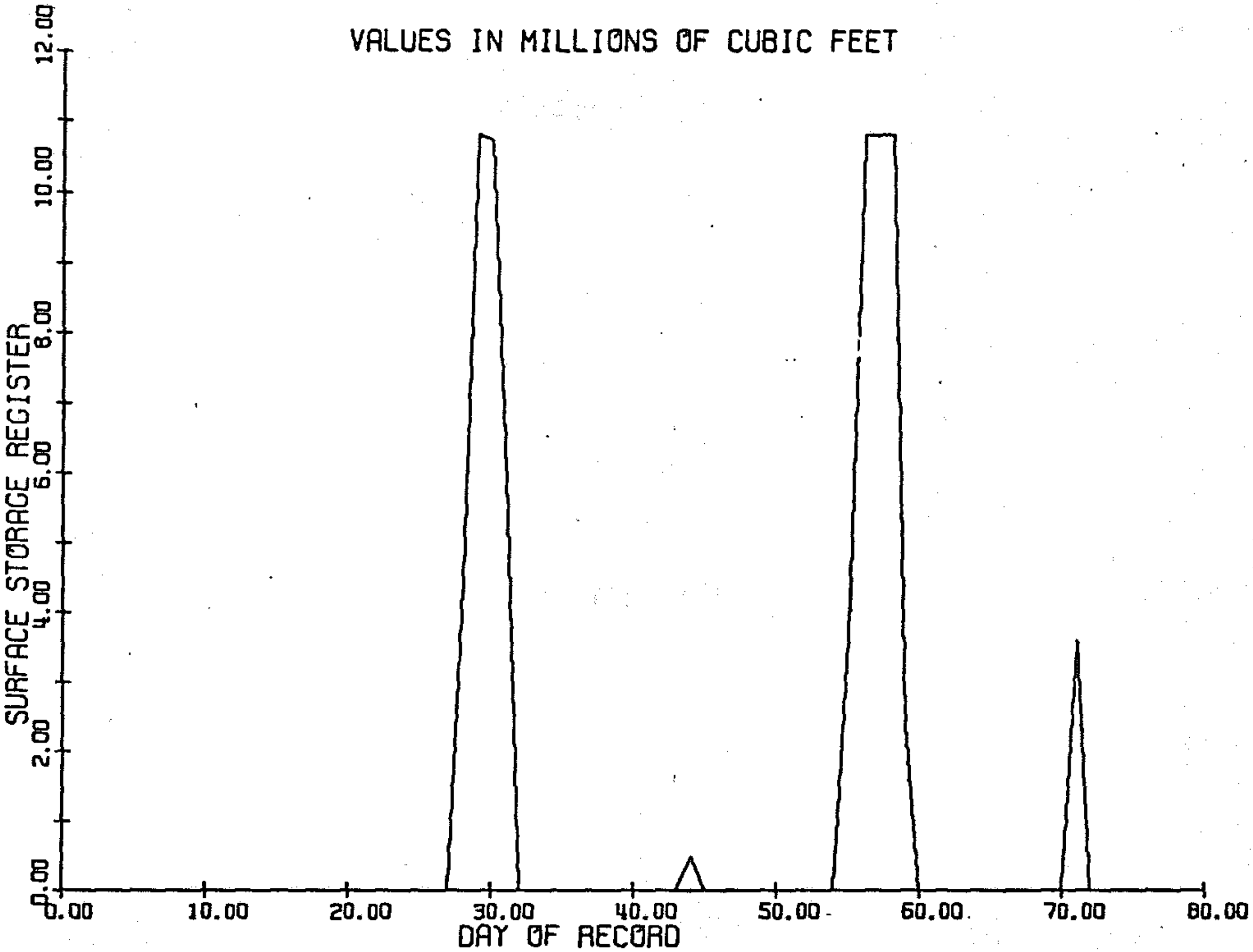

Figure 18: Plot of Volume Storage versus Time for the Surface Storage Component, Storage in Millions of ft^3.

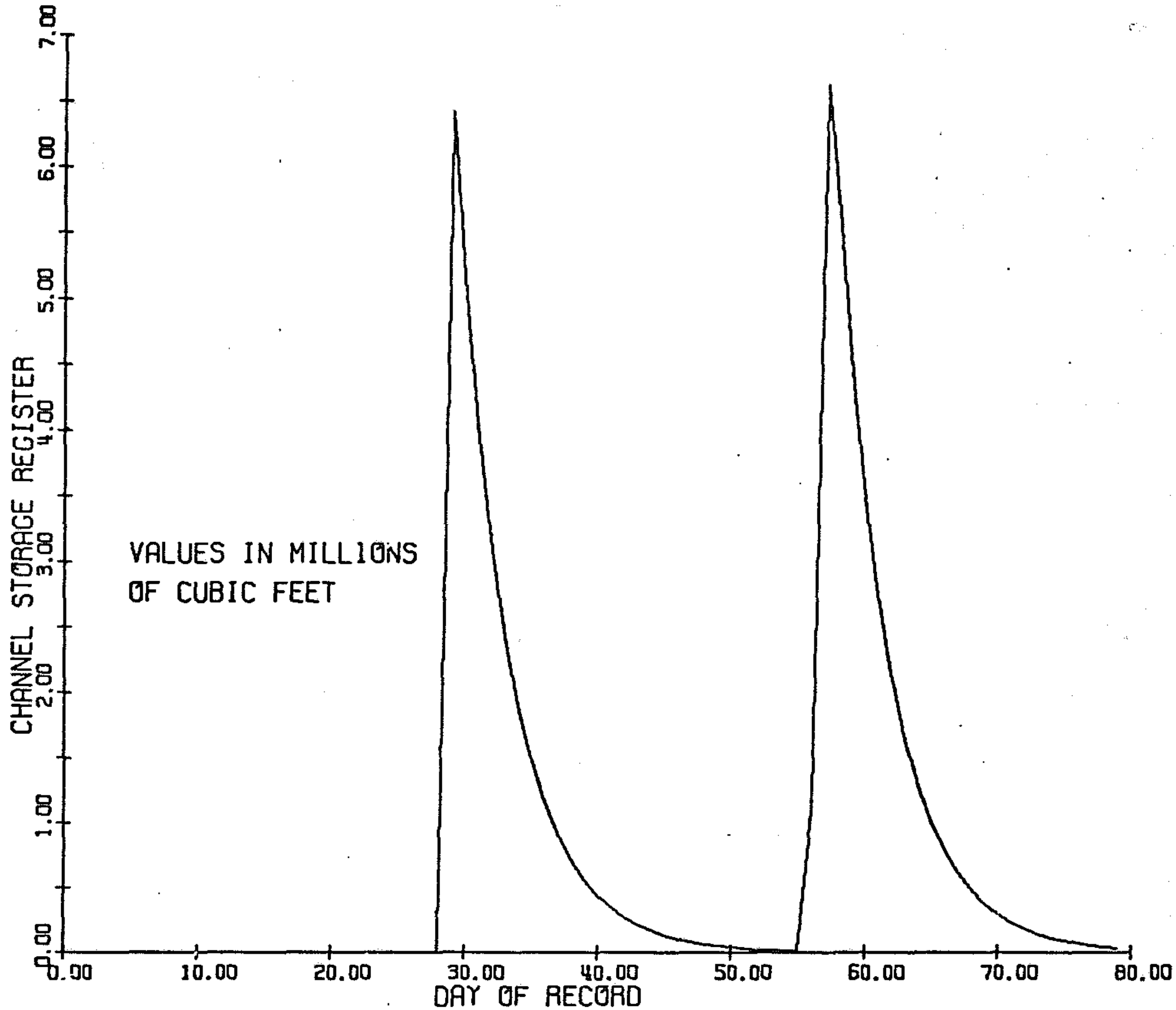

Figure 19: Plot of Volume Storage versus Time for the Channel Storage Component, Storage in Millions of ft^3.

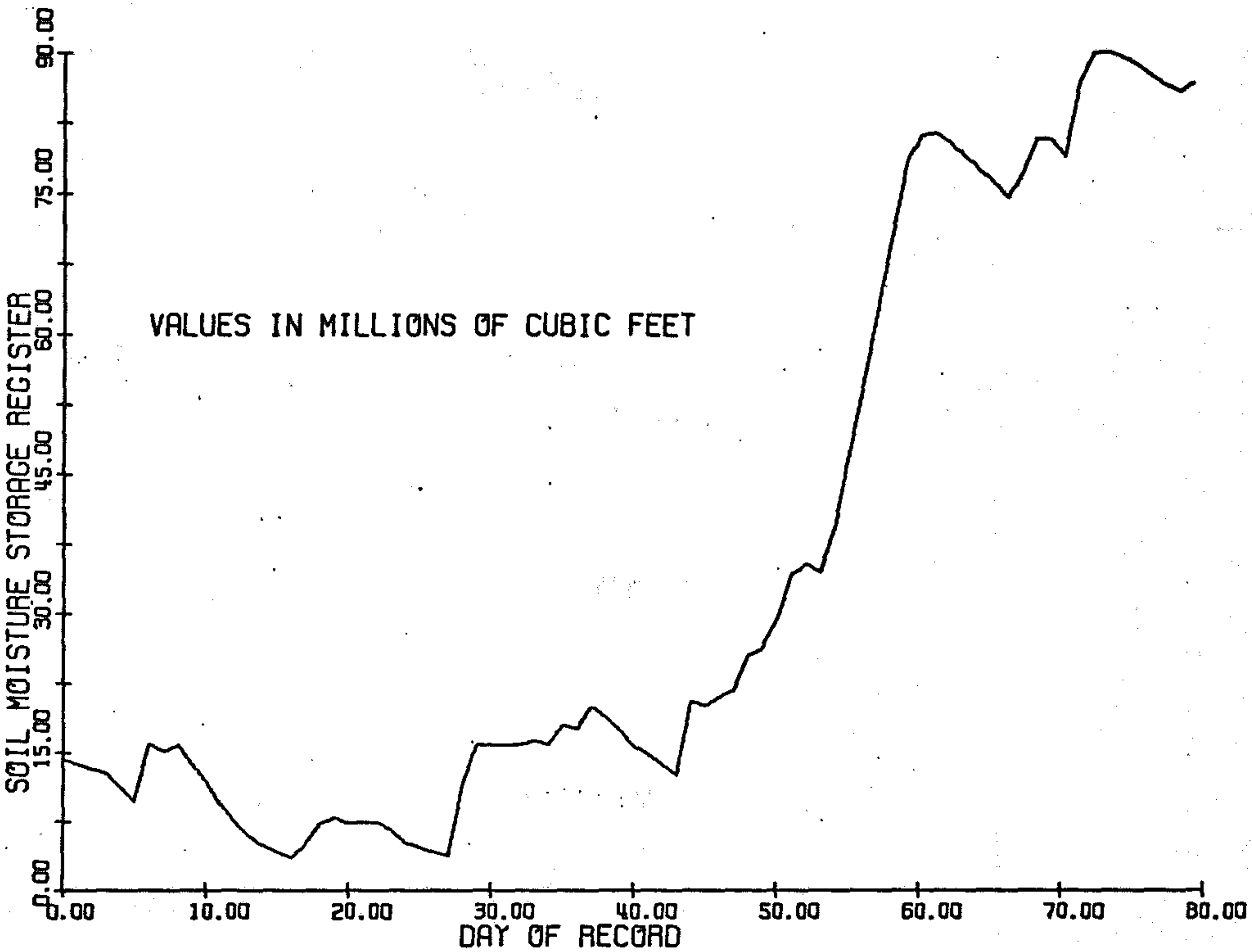

Figure 20: Plot of Volume Storage versus Time for the Soil Moisture Storage Component, Storage in Millions of ft^3.

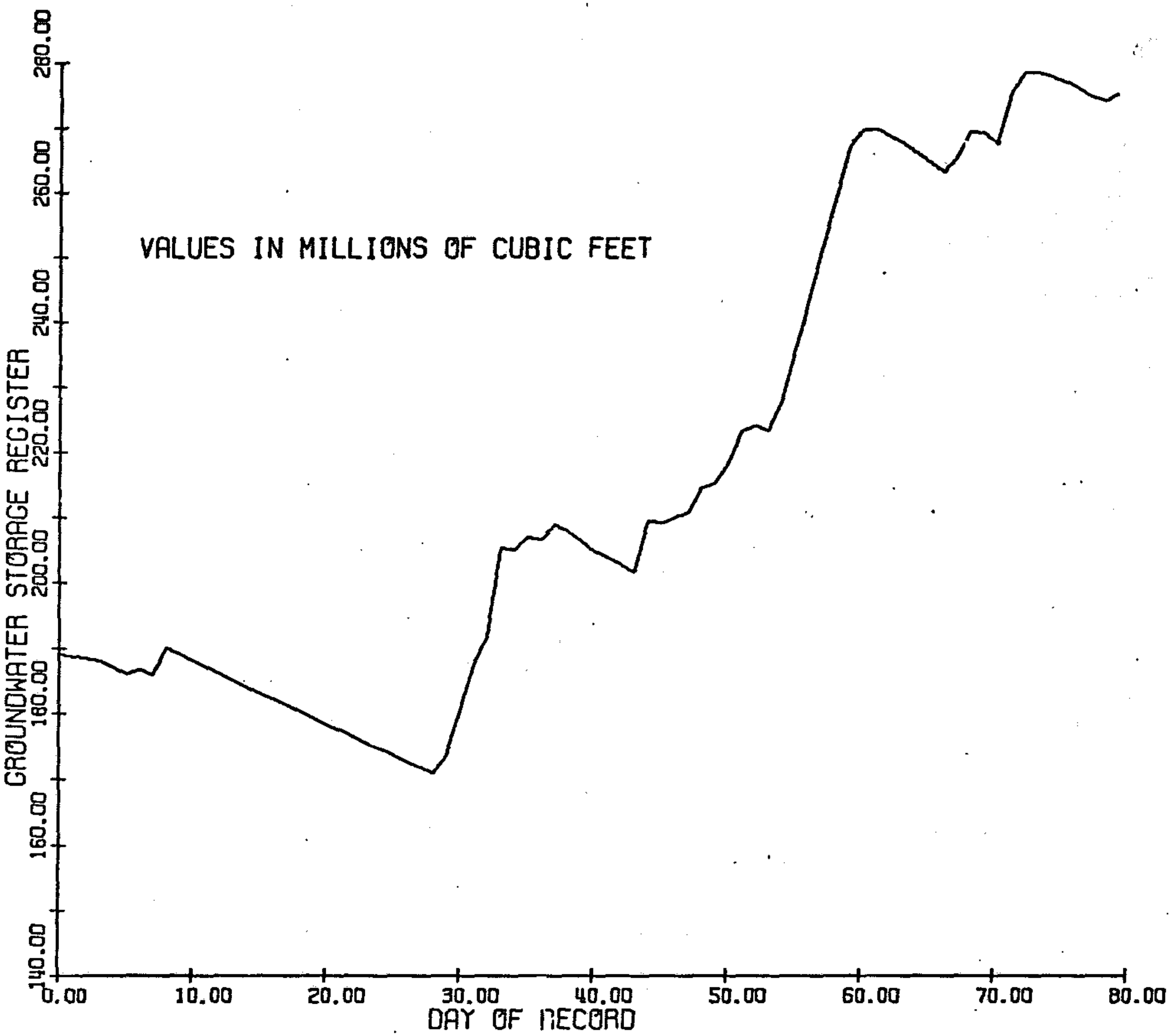

Figure 21: Plot of Volume Storage versus Time for the Groundwater Storage Component, Storage in Millions of ft^3.

Day 80. Such a dramatic increase seems to be a bit out of order and leads to suspicion of some disorder in the model. On the other hand, an examination of the streamflow indicates that the base flow does seem to rise from a level after the storm at Day 32 to a new higher level at Day 60. Examination of the precipitation record indicates a great deal of precipitation did occur throughout the summer which probably held down the potential evapotranspiration rate, kept the soil in quite a wet state and led to considerable amount of groundwater recharge. It should be kept in mind, however, that the soil was prevented from excessively draining into the groundwater storage register by the fact that the groundwater storage has exceeded its threshold value. These unusual occurrences indicate that further improvement of the model might look at the soil-groundwater component combination. This question illustrates the problem with any modeling effort in which several arrangements of the model can lead to essentially the same results. The ultimate answer, of course, is the expansion of the measurement activity which would lead to a verification or refutation of the model as it is presently constructed.

In summary then, the surface and channel portion of the model seem to be operating as might be expected. The soil and groundwater portion seem to indicate some discrepancy and a need for more study in combination with more intensive measurements in the field to verify the results indicated by the model. It seems that the parameters of the model are in fairly good balance. Several of the parameters do dominate the other parts of the model. This may be inherent in the makeup of the watershed or it may be merely a poor indication caused by the particular set of data for which the model was operated. This question can be resolved by application of the model to further years of runoff data and to perhaps to more intensive measurements on several sub-areas of the watershed.

Results of this initial modeling development work and application of the model to 1971 data at Caribou-Poker Creek suggests several points. First, modeling seems to be a well-founded and useful tool for predicting and understanding watershed processes. Second, it leads to several conclusions which suggest either improvement of the model or further field clarification of several components to either confirm the accuracy of the model or suggest its change. Third, it must be emphasized that one year of data with three storms is not fully adequate to demonstrate a six parameter model. It is strongly urged, therefore, that further investigation be undertaken to demonstrate and modify the model with further data.

One final word in closing. It has been clearly indicated in several sections of the report that a modeling activity of a complex natural process such as a watershed can only be a gross estimation at best. Further, because of the wide variety of tools and measurements which are available in various parts of the world, any modeling activity will be largely a creation of the investigator. It is hoped that the model which is proposed here will not be used as the final explanation of the hydrologic processes at the Caribou-Poker Creek watershed. Rather, it should serve as an impetus to further work, it should cause other investigators to question the accuracy of the model, to make suggestions for its improvement, either by expansion of one or more of the components, or to restructure it; or, to simplify one or more of the components. It should also lead to further field work which will verify or disprove various aspects of the model. If the model will accomplish this, the writer feels it will have served its purpose which is to bring together many diverse disciplines which are necessary to study the watershed and to provide a focus for the diverse field measurement and analytic efforts.

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APPENDICES

APPENDIX A

OBSERVED AND CALCULATED CLIMATOLOGICAL DATA

TABLE A-1: Meteorological Data and Observed Runoff.

Date	Day	Air Temp. [°F]	Δ/γ [0]	Water Density [g/cm^3]	Saturated Vapor Pressure [lb/in^2]	Solar Radiation [langleys/hr]	Relative Humidity [0]	Precipitation [in/day]	Potential Evapotranspiration [in/day]	Observed Runoff [ft^3/sec]
6/15/71	1	53.	1.36	0.9995	0.19888	3.35	0.530	.0	.07	11.4
6/16/71	2	56.	1.48	0.9994	0.22188	3.35	0.510	.0	.08	11.1
6/17/71	3	58.	1.58	0.9992	0.23849	3.36	0.460	.0	.09	10.9
6/18/71	4	57.	1.54	0.9993	0.23006	3.36	0.500	.01	.08	10.9
6/19/71	5	60.	1.70	0.9990	0.25618	3.36	0.650	.43	.06	12.5
6/20/71	6	62.	1.80	0.9989	0.27502	3.36	0.670	.02	.06	14.5
6/21/71	7	63.	1.84	0.9987	0.28488	3.36	0.680	.34	.06	14.2
6/22/71	8	67.	2.08	0.9983	0.32750	3.37	0.490	.0	.10	16.6
6/23/71	9	72.	2.41	0.9978	0.38856	3.36	0.510	.0	.10	13.3
6/24/71	10	68.	2.14	0.9982	0.33900	3.36	0.240	.0	.15	12.0
6/25/71	11	70.	2.27	0.9980	0.36304	3.36	0.240	.0	.15	11.4
6/26/71	12	70.	2.27	0.9980	0.36304	3.36	0.250	.0	.15	11.0
6/27/71	13	67.	2.08	0.9983	0.32750	3.35	0.370	.0	.12	10.9
6/28/71	14	58.	1.58	0.9992	0.23849	3.35	0.330	.0	.11	10.9
6/29/71	15	48.	1.15	0.9998	0.16517	3.34	0.560	.03	.06	10.6
6/30/71	16	42.	0.96	1.0000	0.13145	3.34	0.700	.11	.03	10.1
7/01/71	17	48.	1.15	0.9998	0.16517	3.32	0.760	.14	.03	10.4
7/02/71	18	52.	1.30	0.9996	0.19169	3.31	0.810	.06	.02	10.9
7/03/71	19	58.	1.58	0.9992	0.23849	3.30	0.690	.02	.05	10.4
7/04/71	20	56.	1.48	0.9994	0.22188	3.29	0.680	.06	.05	10.1
7/05/71	21	59.	1.64	0.9991	0.24720	3.27	0.710	.05	.05	10.1
7/06/71	22	61.	1.74	0.9990	0.26545	3.26	0.530	.0	.08	9.6
7/07/71	23	63.	1.84	0.9988	0.28488	3.24	0.560	.01	.08	9.6
7/08/71	24	59.	1.64	0.9991	0.24720	3.23	0.670	.0	.05	9.9
7/09/71	25	65.	1.96	0.9985	0.30554	3.21	0.510	.0	.09	9.6
7/10/71	26	66.	2.00	0.9983	0.31636	3.20	0.600	.0	.07	9.6
7/11/71	27	57.	1.54	0.9993	0.23006	3.18	0.810	.62	.03	11.1
7/12/71	28	58.	1.58	0.9992	0.23849	3.16	0.870	.09	.02	22.3

TABLE A-1 (Continued): Meteorological Data and Observed Runoff.

Date	Day	Air Temp. [°F]	Δ/γ [0]	Water Density [g/cm³]	Saturated Vapor Pressure [lb/in²]	Solar Radiation [langleys/hr]	Relative Humidity [0]	Precipi-tation [in/day]	Potential Evapotran-spiration [in/day]	Observed Runoff [ft³/sec]
7/13/71	29	53.	1.36	0.9994	0.19888	3.15	0.840	.39	.02	24.3
7/14/71	30	44.	1.01	1.0000	0.14194	3.13	0.770	.18	.03	24.6
7/15/71	31	47.	1.12	0.9999	0.15907	3.11	0.680	.02	.04	20.8
7/16/71	32	54.	1.39	0.9995	0.20630	3.10	0.650	.08	.05	17.2
7/17/71	33	57.	1.54	0.9993	0.23006	3.07	0.600	.04	.06	16.0
7/18/71	34	65.	1.96	0.9985	0.30554	3.06	0.600	.17	.07	14.8
7/19/71	35	62.	1.80	0.9988	0.27502	3.04	0.550	.06	.08	14.8
7/20/71	36	62.	1.80	0.9988	0.27502	3.03	0.620	.18	.07	13.3
7/21/71	37	52.	1.30	0.9996	0.19169	3.00	0.600	.01	.06	13.6
7/22/71	38	52.	1.30	0.9996	0.19169	2.97	0.570	.0	.06	13.0
7/23/71	39	58.	1.58	0.9992	0.23849	2.96	0.540	.0	.07	12.8
7/24/71	40	58.	1.58	0.9992	0.23849	2.94	0.570	.02	.07	12.8
7/25/71	41	57.	1.54	0.9993	0.23006	2.92	0.690	.0	.05	12.8
7/26/71	42	57.	1.54	0.9993	0.23006	2.90	0.630	.0	.06	12.5
7/27/71	43	52.	1.30	0.9996	0.19169	2.88	0.680	.45	.05	12.8
7/28/71	44	50.	1.23	0.9997	0.17799	2.85	0.630	.01	.05	14.5
7/29/71	45	50.	1.23	0.9997	0.17799	2.82	0.680	.09	.04	13.9
7/30/71	46	52.	1.30	0.9996	0.19169	2.80	0.690	.08	.04	13.3
7/31/71	47	51.	1.27	0.9997	0.18473	2.78	0.820	.20	.02	13.6
8/01/71	48	54.	1.39	0.9995	0.20630	2.75	0.760	.07	.03	13.9
8/02/71	49	50.	1.23	0.9997	0.17799	2.72	0.750	.17	.03	14.2
8/03/71	50	47.	1.12	0.9999	0.15907	2.70	0.690	.28	.04	13.9
8/04/71	51	47.	1.12	0.9999	0.15907	2.68	0.680	.09	.04	15.7
8/05/71	52	47.	1.12	0.9999	0.15907	2.65	0.700	.0	.04	13.6
8/06/71	53	50.	1.23	0.9997	0.17799	2.62	0.760	.27	.03	14.2
8/07/71	54	50.	1.23	0.9997	0.17799	2.60	0.830	.57	.02	18.1
8/08/71	55	51.	1.27	0.9997	0.18473	2.57	0.830	.81	.02	25.6
8/09/71	56	52.	1.30	0.9996	0.19169	2.55	0.830	.75	.02	44.0

TABLE A-1 (Continued): Meteorological Data and Observed Runoff.

Date	Day	Air Temp. [°F]	Δ/γ [0]	Water Density [g/cm³]	Saturated Vapor Pressure [lb/in²]	Solar Radiation [langleys/hr]	Relative Humidity [0]	Precipitation [in/day]	Potential Evapotranspiration [in/day]	Observed Runoff [ft³/sec]
8/10/71	57	48.	1.15	0.9998	0.16517	2.50	0.810	.42	.02	37.4
8/11/71	58	51.	1.27	0.9997	0.18473	2.48	0.670	.0	.05	29.2
8/12/71	59	54.	1.39	0.9995	0.20630	2.45	0.620	.0	.06	24.6
8/13/71	60	48.	1.15	0.9998	0.16517	2.42	0.620	.06	.05	23.3
8/14/71	61	44.	1.01	0.9999	0.14194	2.39	0.570	.0	.05	22.3
8/15/71	62	47.	1.12	0.9999	0.15907	2.36	0.570	.0	.06	21.7
8/16/71	63	53.	1.36	0.9995	0.19888	2.32	0.570	.0	.06	21.4
8/17/71	64	56.	1.48	0.9994	0.22188	2.29	0.610	.0	.06	20.2
8/18/71	65	57.	1.54	0.9993	0.23006	2.27	0.560	.0	.07	19.6
8/19/71	66	54.	1.39	0.9995	0.20630	2.24	0.760	.15	.03	19.3
8/20/71	67	43.	0.98	1.0000	0.13660	2.20	0.970	.19	.00	19.6
8/21/71	68	43.	0.98	1.0000	0.13660	2.17	0.920	.0	.01	20.2
8/22/71	69	49.	1.20	0.9997	0.17148	2.14	0.400	.0	.08	19.3
8/23/71	70	52.	1.30	0.9996	0.19169	2.10	0.790	.58	.03	19.0
8/24/71	71	50.	1.23	0.9997	0.17799	2.07	0.810	.0	.02	16.6
8/25/71	72	49.	1.20	0.9997	0.17148	2.04	0.810	.03	.02	15.4
8/26/71	73	50.	1.23	0.9997	0.17799	2.01	0.810	.0	.02	15.1
8/27/71	74	50.	1.23	0.9997	0.17799	1.97	0.740	.0	.03	14.2
8/28/71	75	52.	1.30	0.9996	0.19169	1.95	0.650	.0	.05	13.9
8/29/71	76	52.	1.30	0.9996	0.19169	1.92	0.680	.0	.05	13.6
8/30/71	77	54.	1.39	0.9995	0.20630	1.89	0.740	.01	.04	13.6
8/31/71	78	46.	1.08	0.9999	0.15317	1.85	0.840	.06	.02	13.6

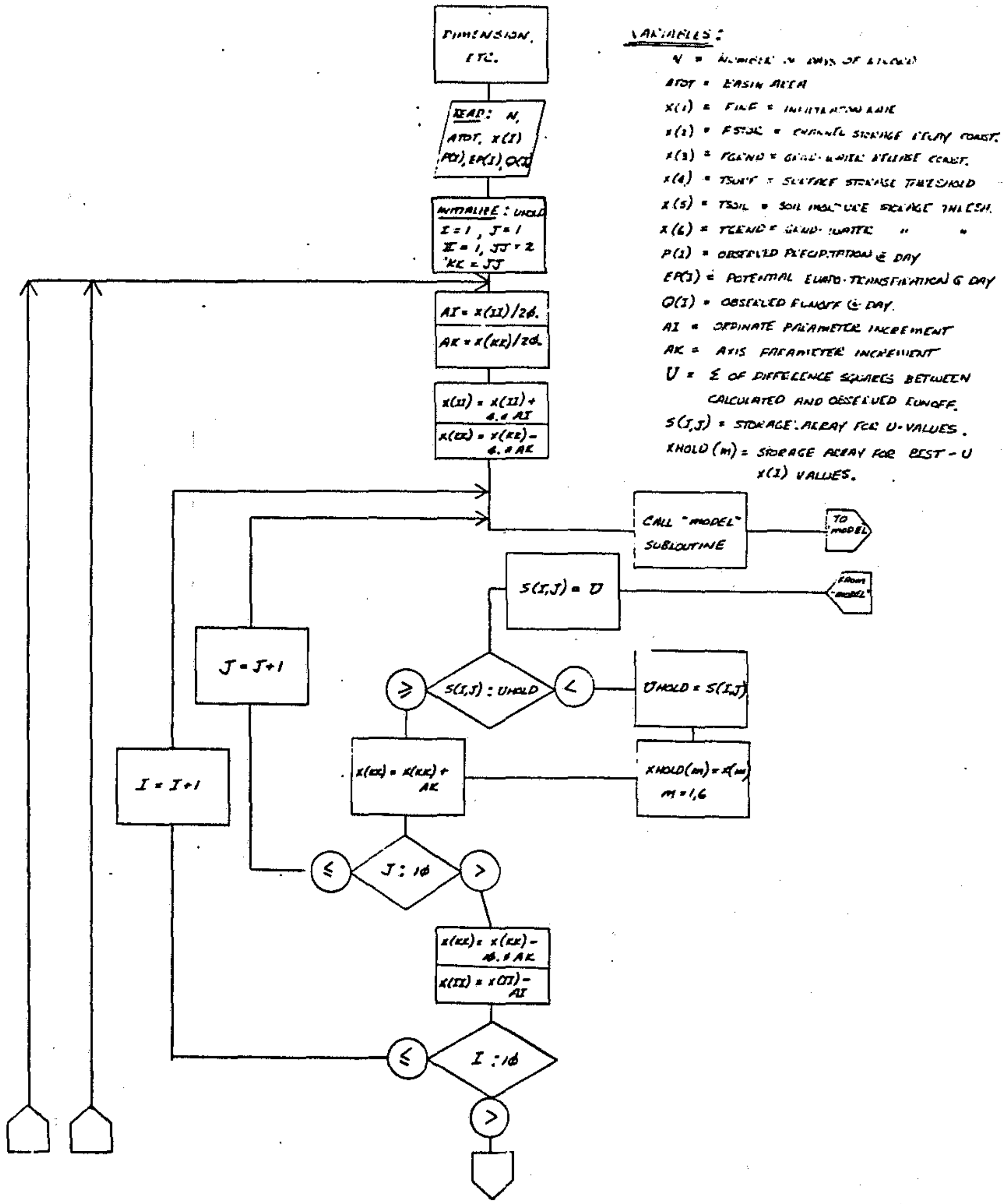
Note: Wind speed assumed 5 mi/hr each day

APPENDIX B

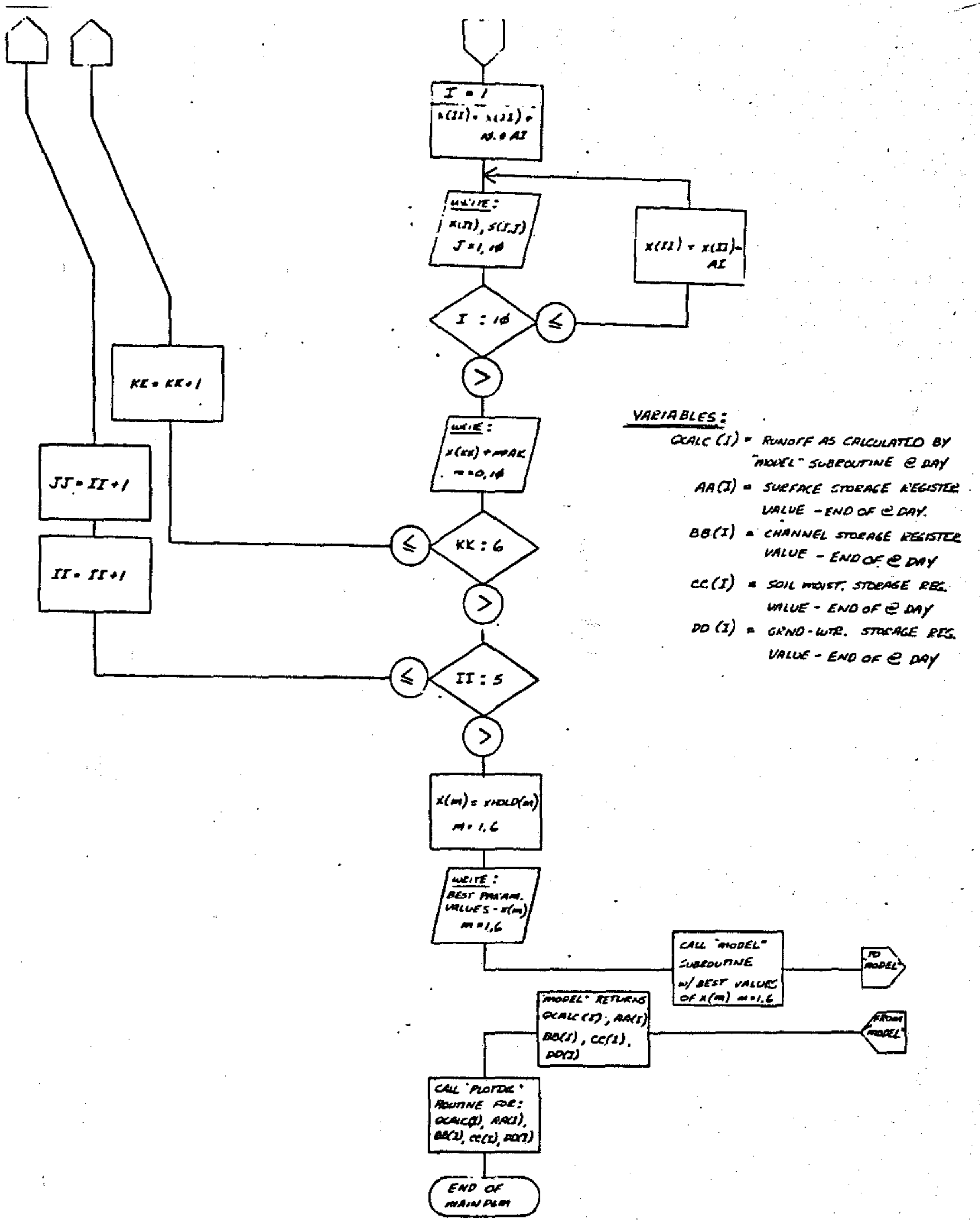
FLOW DIAGRAM OF THE COMPUTATIONAL PROGRAMS

B-1:

FLOW CHART CARIBOU - POKER CREEK WATERSHED MODEL



B-2:

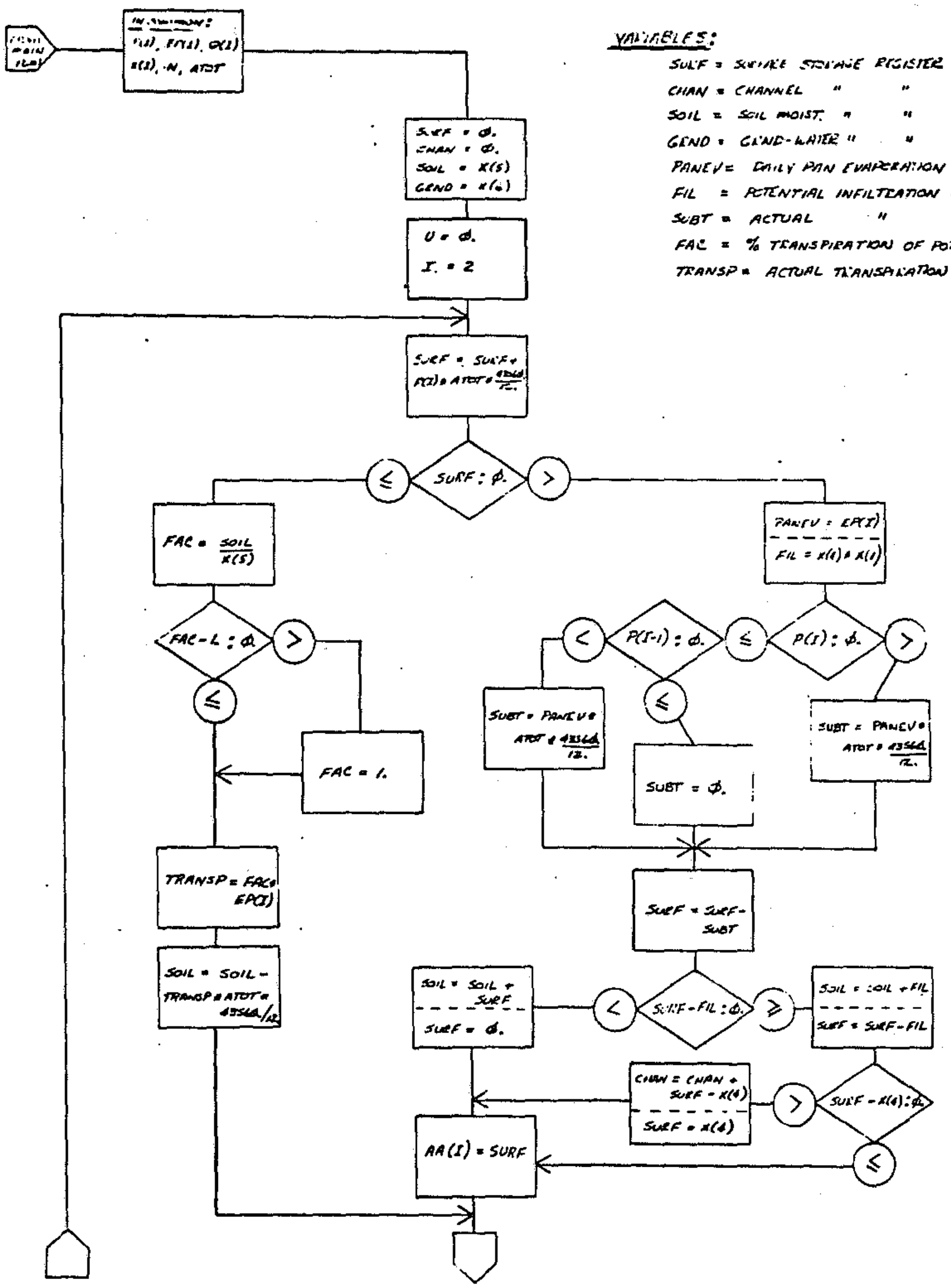

I = 1
X(II) = X(II) + 10.0 AI
WRITE:
X(II), S(I,J)
J = 1, 10
X(II) = X(II) - AI
I : 10
≤
>
KK = KK + 1
WRITE:
X(KK) + M·AK
M = 0, 10
JJ = II + 1
II = II + 1
KK : 6
II : 5
X(M) = XHOLD(M)
M = 1,6
WRITE:
BEST PARAM.
VALUES - X(M)
M = 1,6
CALL "MODEL" SUBROUTINE W/ BEST VALUES OF X(M) M=1,6
TO MODEL
FROM MODEL
"MODEL" RETURNS QCALC(I), AA(I), BB(I), CC(I), DD(I)
CALL "PLOTDG" ROUTINE FOR: QCALC(I), AA(I), BB(I), CC(I), DD(I)
END OF MAIN PGM
VARIABLES:
QCALC (I) = RUNOFF AS CALCULATED BY "MODEL" SUBROUTINE @ DAY
AA(I) = SURFACE STORAGE REGISTER VALUE - END OF @ DAY.
BB(I) = CHANNEL STORAGE REGISTER VALUE - END OF @ DAY
CC(I) = SOIL MOIST. STORAGE REG. VALUE - END OF @ DAY
DD (I) = GRND-WTR. STORAGE REG. VALUE - END OF @ DAY

B-3:

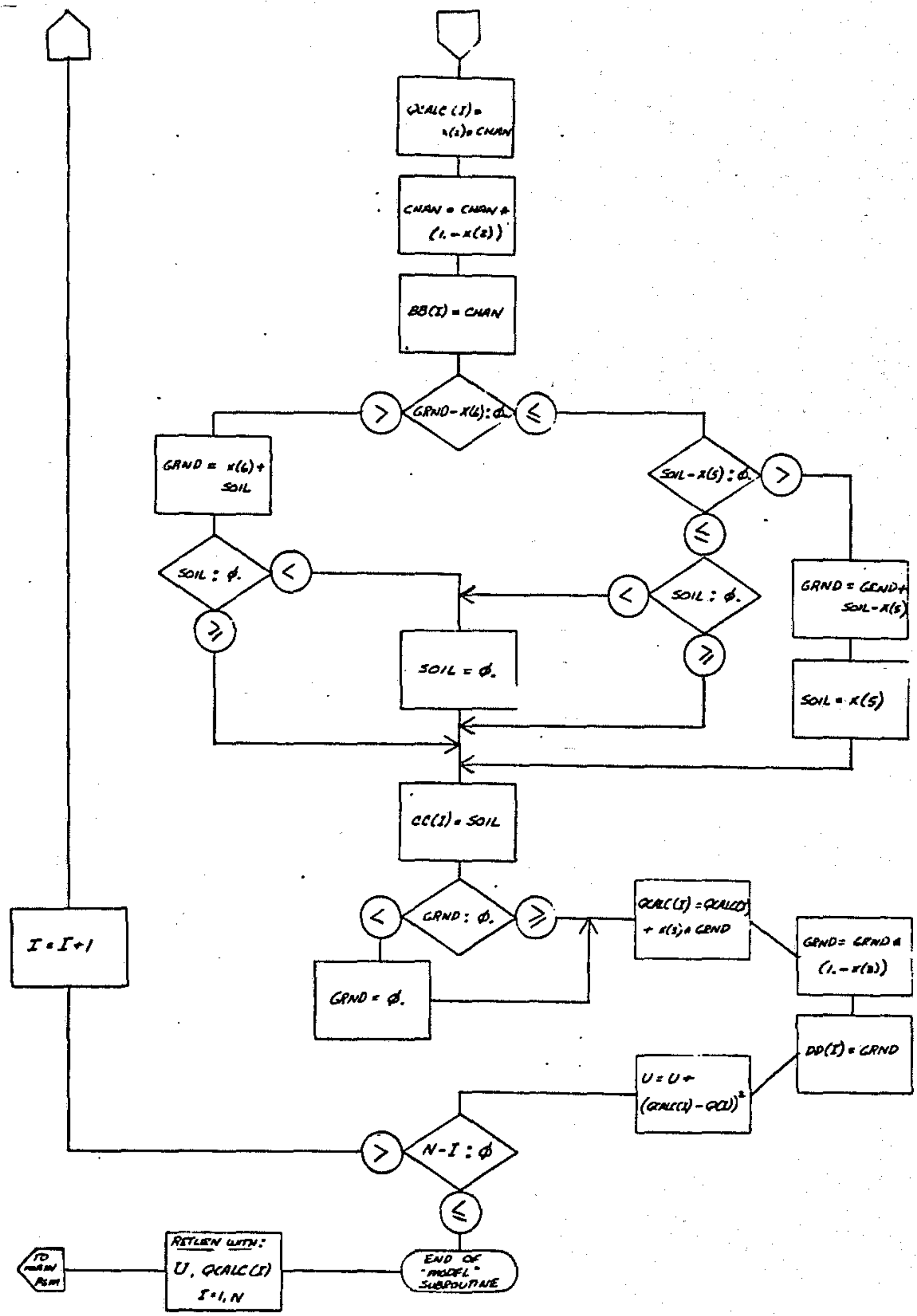
"MOIST" SUBROUTINE CARIBOU-POKER CREEK WATERSHED MODEL

VARIABLES:

SURF = SURFACE STORAGE REGISTER
CHAN = CHANNEL " "
SOIL = SOIL MOIST. " "
GRND = GRND-WATER " "
PANEV = DAILY PAN EVAPORATION
FIL = POTENTIAL INFILTRATION AMT.
SUBT = ACTUAL " "
FAC = % TRANSPIRATION OF POTENTIAL
TRANSP = ACTUAL TRANSPIRATION AMT.



B-4: —


QCALC (I) = X(2) * CHAN
CHAN = CHAN * (1. - X(2))
BB(I) = CHAN
GRND - X(6) : Ø.
GRND = X(6) + SOIL
SOIL - X(5) : Ø.
SOIL : Ø.
SOIL : Ø.
GRND = GRND + SOIL - X(5)
SOIL = Ø.
SOIL = X(5)
CC(I) = SOIL
GRND : Ø.
QCALC(I) = QCALC(I) + X(3) * GRND
GRND = GRND * (1. - X(3))
GRND = Ø.
I = I + 1
DD(I) = GRND
U = U + (QCALC(I) - Q(I))^2
N - I : Ø
RETURN WITH: U, QCALC(I) I = 1, N
END OF "MODEL" SUBROUTINE
TO MAIN PGM

APPENDIX C

THE FORTRAN PROGRAM FOR THE CARIBOU-POKER CREEK RESEARCH WATERSHED MODEL

C-1:


```
      C
      C
      C
      C CARIBOU - POKER CREEK WATERSHED MODEL  -  PARAMETER MAPPING
      C
      C
      C
            DIMENSIONX(6),P(90),EP(90),Q(90),S(10,10),XX(10),QCALC(90)
            DIMENSIONXNAME(4),YNAME(3),TITL1(9),TITL2(4),TITL3(9),TITL4(4)
            DIMENSIONTITL5(4),TITL6(4),TITL7(4),TITL8(4),TITL9(4),TITLA(4)
            DIMENSIONXHOLD(6),MESG1(11),ENAME(5),FNAME(4),ZNAME(6),TNAME(8)
            DIMENSIONVNAME(6),UNAME(8),SNAME(7),AA(90),BB(90),CC(90),DD(90)
            COMMON/WTHR/P,EP,Q,X,U,ATOT,N,QCALC,AA,BB,CC,DD
      C
      C
      C DATA INPUT FOLLOWS
      C
      C
            UHOLD=2000.
            READ(1,10)N,ATOT
         10 FORMAT(I3,F7.2)
            WRITE(3,11)N,ATOT
         11 FORMAT (T20, 'NUMBER OF DAYS OF RECORD = ',I3,10X,'BASIN AREA = ',
           1F7.2,'ACRES'///)
            READ (1,14)(X(I),I=1,6)
         14 FORMAT(3F6.4,2F10.1,F10.0)
            WRITE(3,16)(X(I),I=1,6)
         16 FORMAT(T40,'INITIAL PARAMETER VALUES'/T4,'X(1)=FINF=',F6.4,4X,
           1'X(2)=FSTOR=',F6.4,4X,'X(3)=FGRND=',F6.4,4X,'X(4)=TSURF=',
           2F10.1,'X(5)=TSOIL=',F10.1,'X(6)=TGRND=',F10.0//)
            N=N+1
            READ(1, 4)(P(I),EP(I),Q(I), I=1,N)
          4 FORMAT(T4,F6.3,F8.6,F8.2)
            WRITE(3,5)
          5 FORMAT(//T40,'MET DATA FOR THIS RUN'/T5,'DAY',19X,'PRECIPITATION (
           1IN)',10X,'POTENTIAL EVAPOTRANSPIRATION (IN)',5X,'OBSERVED RONOFF (
           2CFS)')
            WRITE(3, 6)(I,P(I),EP(I),Q(I), I=1,N)
          6 FORMAT(T4,I3,25X,F6.3,25X,F8.6,20X,F10.4)
      C
      C
      C DOUBLE DO LOOP FOLLOWS - GENERATES ONE 10 BY 10 PARAMETER MAP OF
      C U VALUES FOR EACH II AND KK AS THE PARAMETERS INDICATED BY II AND
      C KK ARE VARIED.
      C
      C DURING THE GENERATION OF A MAP WITH TWO PARAMETERS, THE OTHER FOUR
      C PARAMETERS REMAIN FIXED AT INITIAL VALUES.
      C
      C
            DO102II=1,5
            JJ=II+1
            DO100KK=JJ,6
            WRITE(3,22)II,KK
         22 FORMAT(///T10,'PARAMETERS TO BE VARIED THIS ROUND ARE X(',I1,') AN
```

C-2:


```
      10 X(',I1,') - ALL OTHERS HELD FIXED AT INITIAL VALUES'///)
         AI=X(II)/20.
         AK=X(KK)/20.
         X(II)=X(II)+4.*AI
         X(KK)=X(KK)-4.*AK
         WRITE(3,201)
     201 FORMAT(T10,'U - VALUES MAPPED ARE THE SUM OF THE DIFFERENCE SQUARE
        1S BETWEEN OBSERVED AND CALCULATED RUNOFF'///)
         DO40I=1,10
         DO30J=1,10
         CALL MODEL(-1.0)
         S(I,J)=U
C
C BEST U VALUE AND ITS GENERATING PARAMETERS ARE STORED FOR FUTURE USE
C
         IF(S(I,J)-UHOLD)32,38,38
      32 UHOLD=S(I,J)
         DO36M=1,6
         XHOLD(M)=X(M)
      36 CONTINUE
      38 CONTINUE
         X(KK)=X(KK)+AK
      30 CONTINUE
         X(KK)=X(KK)-10.*AK
         X(II)=X(II)-AI
      40 CONTINUE
         X(II)=X(II)+10.*AI
      50 FORMAT(' ',T12,E10.3,10X,10(F6.0,4X)///)
         WRITE(3,50)X(II),(S(1,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(2,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(3,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(4,J),J=1,10)
         X(II)=X(II)-AI
      52 FORMAT(' ',3X,'X(',I1,')',3X,E10.3,10X,10(F6.0,4X)///)
         WRITE(3,52)II,X(II),(S(5,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(6,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(7,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(8,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(9,J),J=1,10)
         X(II)=X(II)-AI
         WRITE(3,50)X(II),(S(10,J),J=1,10)
         XX(1)=X(KK)
         DO55L=2,10
         XX(L)=XX(L-1)+AK
      55 CONTINUE
         WRITE(3,56)(XX(L),L=1,10),KK
      56 FORMAT(///' ',27X,10F10.3   //T70,'X(',I1,')')
```

C-3:


```
0077              X(II)=X(II)+5.*AI
0078              X(KK)=X(KK)+4.*AK
0079              WRITE(3,58)II,X(II),KK,X(KK)
0080           58 FORMAT(///T4,'END OF ROUND   -  X(',I1,') =',E9.2,10X,'X(',I1,
                 1') =',E9.2/////)
0081          100 CONTINUE
0082          102 CONTINUE
        C
        C
        C CALL MODEL SUBROUTINE WITH BEST VALUES OF PARAMETERS FROM ABOVE.
        C
        C
0083              WRITE(3,17)(XHOLD(I),I=1,6)
0084           17 FORMAT(T40,  'FINAL PARAMETER VALUES'/T4,'X(1)=FINF=',F6.4,4X,
                 1'X(2)=FSTOR=',F6.4,4X,'X(3)=FGRND=',F6.4,4X,'X(4)=TSURF=',
                 2F10.1,'X(5)=TSOIL=',F10.1,'X(6)=TGRND=',F10.0//)
0085              DO 431 M=1,6
0086              X(M)=XHOLD(M)
0087          431 CONTINUE
0088              WRITE(3,165)U
0089          165 FORMAT(T20,'BEST U VALUE THIS ROUND WITH PARAMETER VALUES FROM ABO
                 1VE =',F10.0///)
        C
        C
        C   ROUTINE FOR PLOTTING OBSERVED VS. CALCULATED RUNOFF FOLLOWS.
        C
        C
0090              CALL PLOTDK
0091              CALL PLOT(0.5,0.5,3)
0092              READ(1,700)(XNAME(I),I=1,4)
0093          700 FORMAT(4A4)
0094              READ(1,701)(YNAME(I),I=1,3)
0095          701 FORMAT(3A4)
0096              CALL AXIS(0.5,0.5,XNAME,-13,8.,0.,0.,10.,10.)
0097              CALL AXIS(0.5,0.5,YNAME,11,6.,90.,0.,10.,10.)
0098              B=Q(2)*0.1+0.5
0099              CALL PLOT(0.6,B,3)
0100              DO706I=3,N
0101              B=Q(I)*0.1+0.5
0102              AI=FLOAT(I)*0.1+0.5
0103              CALL PLOT(AI,B,2)
0104          706 CONTINUE
0105              READ(1,702)(TITL1(I),I=1,4)
0106          702 FORMAT(4A4)
0107              B=Q(N-4)*0.1+0.5
0108              CALL PLOT(8.0,B,3)
0109              CALL PLOT(7.5,1.0,2)
0110              CALL PLOT(8.0,1.0,2)
0111              CALL SYMBOL(8.1,1.0,0.07,TITL1,0.,16)
0112              B=QCALC(2)*0.1+0.5
0113              CALL PLOT(0.6,B,3)
0114              DO705I=3,N
0115              B=QCALC(I)*0.1+0.5
0116              AI=FLOAT(I)*0.1+0.5
```

C-4:


```
              CALL PLOT(AI,B,2)
          705 CONTINUE
              READ(1,703)(TITL2(I),I=1,5)
          703 FORMAT(5A4)
              B=QCALC(N-4)*0.1+0.5
              CALL PLOT(8.0,B,3)
              CALL PLOT(7.5,3.5,2)
              CALL PLOT(8.0,3.5,2)
              CALL SYMBOL(8.1,3.5,0.07,TITL2,0.,20)
              READ(1,800)(TITL3(I),I=1,9)
          800 FORMAT(9A4)
              CALL SYMBOL(2.5,6.0,0.21,TITL3,0.,36)
              CALL PLOT(2.5,5.9,3)
              CALL PLOT(3.7,5.9,2)
              CALL PLOT(4.3,5.9,3)
              CALL PLOT(5.2,5.9,2)
              CALL PLOT(5.4,5.9,3)
              CALL PLOT(6.2,5.9,2)
              CALL PLOT(6.4,5.9,3)
              CALL PLOT(7.5,5.9,2)
              CALL PLOT(7.7,5.9,3)
              CALL PLOT(8.6,5.9,2)
              READ(1,801)(TITL4(I),I=1,4)
          801 FORMAT(4A4)
              CALL SYMBOL(0.8,5.5,0.14,TITL4,0.,16)
              READ(1,801)(TITL5(I),I=1,4)
              READ(1,801)(TITL6(I),I=1,4)
              READ(1,801)(TITL7(I),I=1,4)
              READ(1,801)(TITL8(I),I=1,4)
              READ(1,801)(TITL9(I),I=1,4)
              READ(1,801)(TITLA(I),I=1,4)
              READ(1,809)(MESG1(I),I=1,11)
          809 FORMAT(11A4)
              CALL SYMBOL(0.8,5.2,0.07,TITL5,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(1),0.,4)
              CALL SYMBOL(0.8,5.0,0.07,TITL6,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(2),0.,4)
              CALL SYMBOL(0.8,4.8,0.07,TITL7,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(3),0.,4)
              X(4)=X(4)/1000000.
              CALL SYMBOL(0.8,4.6,0.07,TITL8,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(4),0.,3)
              X(5)=X(5)/1000000.
              CALL SYMBOL(0.8,4.4,0.07,TITL9,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(5),0.,3)
              X(6)=X(6)/1000000.
              CALL SYMBOL(0.8,4.2,0.07,TITLA,0.,16)
              CALL NUMBER(-0.0,-0.0,-0.0,X(6),0.,3)
              CALL SYMBOL(0.8,4.0,0.07,MESG1,0.,44)
              READ(1,804)MESG2
          804 FORMAT(A4)
              CALL SYMBOL(1.2,3.5,0.14,MESG2,0.,4)
              CALL NUMBER(-0.0,-0.0,-0.0,U,0.,-1)
              CALL PLOT(0.,0.,100)
```

C-5:


```
C
C
C     PLOTTING ROUTINE FOR PLOTTING SURFACE STORAGE FOLLOWS
C
C
            CALL PLOTOK
            CALL PLOT(0.,0.,3)
            READ(1,820)(ZNAME(I),I=1,6)
        820 FORMAT(6A4)
            CALL AXIS(0.,0.,XNAME,-13,8.,0.,0.,10.,10.)
            CALL AXIS(0.,0.,ZNAME,24,6.,90.,0.,2.,20.)
            CALL PLOT(0.,0.,3)
            AA(1)=0.
            DO 825 I=1,N
            B=AA(I)/2000000.
            AI=FLOAT(I)*0.1
            CALL PLOT (AI,B,2)
        825 CONTINUE
            READ(1,826)(TNAME(I),I=1,8)
        826 FORMAT(8A4)
            CALL SYMBOL(2.0,6.0,0.14,TNAME,0.,32)
            CALL PLOT(0.,0.,100)
C
C
C     PLOTTING ROUTINE FOR PLOTTING CHANNEL STORAGE FOLLOWS
C
C
            READ(1,820)(VNAME(I),I=1,6)
            CALL PLOTOK
            CALL PLOT(0.,0.,3)
            CALL AXIS(0.0,0.0,XNAME,-13,8.,0.,0.,10.,10.)
            CALL AXIS(0.,0.,VNAME,24,7.,90.,0.,1.,20.)
            CALL PLOT(0.,0.,3)
            BB(1)=0.
            DO 827 I=1,N
            B=BB(I)/1000000.
            AI=FLOAT(I)*0.1
            CALL PLOT(AI,B,2)
        827 CONTINUE
            READ(1,703)(ENAME(I),I=1,5)
            READ(1,801)(FNAME(I),I=1,4)
            CALL SYMBOL(0.5,3.0,0.14,ENAME,0.,20)
            CALL SYMBOL(0.5,2.7,0.14,FNAME,0.,16)
            CALL PLOT(0.,0.,100)
C
C
C     PLOTTING ROUTINE FOR PLOTTING SOIL MOISTURE STORAGE FOLLOWS
C
C
            READ(1,826)(UNAME(I),I=1,8)
            CALL PLOTOK
            CALL PLOT(0.,0.,3)
            CALL AXIS(0.0,0.0,XNAME,-13,8.,0.,0.,10.,10.)
            CALL AXIS(0.,0.,UNAME,32,6.,90.,0.,15.,20.)
```

C-6:

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```
                  CALL PLOT(0.,0.,3)
                  B=CC(2)/15000000.
                  CALL PLOT(0.,B,3)
                  DO 828 I=3,N
                  B=CC(I)/15000000.
                  AI=FLOAT(I)*0.1
                  CALL PLOT(AI,B,2)
              828 CONTINUE
                  CALL SYMBOL(0.6,4.0,0.14,TNAME,0.,32)
                  CALL PLOT(0.,0.,100)
            C
            C
            C     PLOTTING ROUTINE FOR PLOTTING GROUNDWATER STORAGE FOLLOWS
            C
            C
                  READ(1,830)(SNAME(I),I=1,7)
              830 FORMAT(7A4)
                  CALL PLOTDK
                  CALL PLOT(0.,0.,3)
                  CALL AXIS(0.0,0.0,XNAME,-13,8.,0.,0.,10.,10.)
                  CALL AXIS(0.,0.,SNAME,28,7.,90.,140.,20.,20.)
                  B=(DD(2)/20000000.)-7.
                  CALL PLOT(0.,B,3)
                  DO 836 I=3,N
                  B=(DD(I)/20000000.)-7.
                  AI=FLOAT(I)*0.1
                  CALL PLOT(AI,B,2)
              836 CONTINUE
                  CALL SYMBOL(0.6,5.5,0.14,TNAME,0.,32)
                  CALL PLOT(0.,0.,100)
                  CALL EXIT
                  END
```

C-7:


```
      C
      C
      C
      C SUBROUTINE MODEL FOLLOWS
      C
      C
      C
            SUBROUTINE MODEL(A)
            DIMENSIONX(6),P(90),EP(90),Q(90),QCALC(90),AA(90),BB(90),CC(90)
            DIMENSION DD(90)
            COMMON/WTHR/P,EP,Q,X,U,ATOT,N,QCALC,AA,BB,CC,DD
            IF (A)2,3,3
          2 SURF=0.0
            CHAN=0.0
            U=0.0
            SOIL=X(5)
            GRND = X(6)
          3 CONTINUE
         21 I=2
         22 CONTINUE
         25 SURF=SURF+(P(I)*ATOT*43560./12.)
            IF(SURF)70,70,30
         30 CONTINUE
      C
      C THE FOLLOWING STATEMENTS ARE THE RIGHT BRANCH OF DECISION 1
      C
            PANEV=EP(I)
            FIL=X(4)*X(1)
            IF(P(I))36,36,34
         34 SUBT=(PANEV*ATOT*43560./12.)
            GO TO 50
         36 IF(P(I-1))40,40,38
         38 SUBT=(PANEV*ATOT*43560./24.)
            GO TO 50
         40 SUBT=0.0
         50 CONTINUE
            SURF=SURF-SUBT
            IF(SURF-FIL)52,61,61
         52 SOIL=SOIL+SURF
            SURF=0.0
            GO TO 60
         61 SOIL=SOIL+FIL
            SURF=SURF-FIL
            IF(SURF-X(4))60,60,58
         58 CHAN = CHAN+SURF-X(4)
            SURF=X(4)
         60 CONTINUE
            AA(I)=SURF
            GO TO 100
         70 CONTINUE
      C
      C THE FOLLOWING STATEMENTS ARE THE LEFT BRANCH OF DECISION 1
      C
            FAC=SOIL/X(5)
```

C-8:


```
      IF(FAC-1.0)73,73,72
   72 FAC=1.0
   73 CONTINUE
      TRANSP = FAC*EP(I)
      SOIL=SOIL-(TRANSP*ATOT*43560./12.)
  100 CONTINUE
      QCALC(I)=X(2)*CHAN
      CHAN=CHAN*(1.-X(2))
      BB(I)=CHAN
C
C DECISION 4 FOLLOWS
C
      IF(GRND-X(6))110,110,104
  104 CONTINUE
      GRND=X(6)+SOIL
      IF(SOIL)149,150,150
  110 CONTINUE
      IF(SOIL-X(5))120,120,112
  112 CONTINUE
      GRND=GRND+SOIL-X(5)
      SOIL=X(5)
      GO TO 150
  120 CONTINUE
      IF(SOIL)149,149,150
  149 SOIL=0.0
  150 CONTINUE
      CC(I)=SOIL
C
C DECISION 7 FOLLOWS
C
      IF(GRND)152,154,154
  152 GRND=0.0
  154 CONTINUE
      QCALC(I)=QCALC(I)+X(3)*GRND
      GRND=GRND*(1.-X(3))
      DD(I)=GRND
      QCALC(I)=QCALC(I)/(24.*3600.)
      U=U+(QCALC(I)-Q(I))**2
      I=I+1
      IF(N-I)170,22,22
  170 CONTINUE
      RETURN
      END
```